Sediment-Hosted Copper Deposits of the World: Deposit Models and Database

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Introduction

This publication contains four descriptive models and four grade-tonnage models for sediment hosted copper deposits. Descriptive models are useful in exploration planning and resource assessment because they enable the user to identify deposits in the field and to identify areas on geologic and geophysical maps where deposits could occur. Grade and tonnage models are used in resource assessment to predict the likelihood of different combinations of grades and tonnages that could occur in undiscovered deposits in a specific area. They are also useful in exploration in deciding what deposit types meet the economic objectives of the exploration company. The models in this report supersede the sediment-hosted copper models in USGS Bulletin 1693 (Cox, 1986, and Mosier and others, 1986) and are subdivided into a general type and three subtypes. The general model is useful in classifying deposits whose features are obscured by metamorphism or are otherwise poorly described, and for assessing regions in which the geologic environments are poorly understood. The three subtypes are based on differences in deposit form and environments of deposition. These differences are described under subtypes in the general model.

Deposit models are based on the descriptions of geologic environments and physical characteristics, and on metal grades and tonnages of many individual deposits. Data used in this study are presented in a database representing 784 deposits in nine continents. This database was derived partly from data published by Kirkham and others (1994) and from new information in recent publications. To facilitate the construction of grade and tonnage models, the information, presented by Kirkham in disaggregated form, was brought together to provide a single grade and a single tonnage for each deposit. Throughout the report individual deposits are defined as being more than 2,000 meters from the nearest adjacent deposit.

The deposit models are presented here as a PDF file. The database can be most conveniently read in FileMaker Pro. For those who do not have the FileMaker application, Microsoft-Excel, tab-delimited-ASCII and comma-separated-value files are included. The reader may be interested in a similar publication on porphyry copper deposits (Singer and others, 2002) also available online.

The authors wish to thank William F. Cannon for his thoughtful review of this report and Berry Moring for generating the deposit-location plot.

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Kirkham, R.V, Carriere, J.J., Laramee, R.M., and Garson, D.F., 1994, Global distribution of sediment-hosted stratiform copper deposits and occurrences: Geological Survey of Canada Open File 2915b, 256 p.

Mosier, D.L., Singer, D.A., and Cox, D.P., 1986, Grade and tonnage model of sediment-hosted copper *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 206. (http://pubs.usgs.gov/bul/b1693/Md30b.pdf)

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DESCRIPTIVE MODEL OF SEDIMENT-HOSTED COPPER

MODEL 30b.1, Replaces Sediment-hosted Copper, 30b (Cox, 1986)

By Dennis P. Cox

APPROXIMATE SYNONYMS

Sandstone copper, shale-hosted copper, redbed Cu, continental redbed, Kupferschiefer type, marine paralic type, reduced-facies Cu, Revett Cu.

DESCRIPTION

Sediment-hosted copper deposits are stratabound, that is, they are restricted to a narrow range of layers within a sedimentary sequence but do not necessarily follow sedimentary bedding. They are epigenetic and diagenetic, that is, they are formed after the host sediment is deposited, but in most cases, prior to lithification of the host. They form independently of igneous processes.

GENERAL REFERENCES

Gustafson and Williams (1981), Lur'ye (1986), Kirkham (1989).

GEOLOGICAL ENVIRONMENT

Rock Types

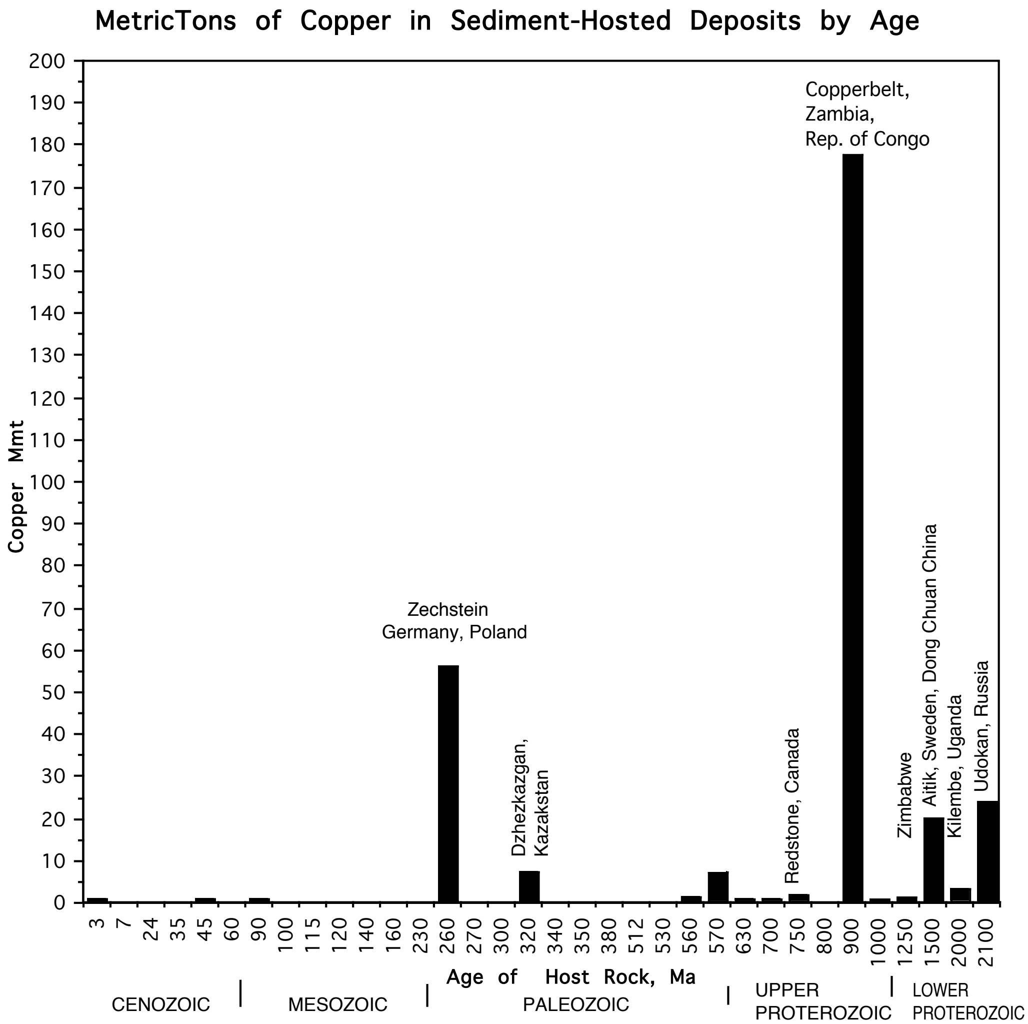
Host rocks are of two types: low-energy calcareous or dolomitic siltstones, shales and carbonate rocks of marine or lacustrine origin; and high-energy sandstones, arkoses and conglomerates of continental origin. Deposits of two distinct types are formed in these host rocks. Respectively they are described in Models 30b.2, reduced facies Cu and 30b.3, redbed Cu that follow this section.

Textures

Low energy rocks are thin-bedded to finely laminated and exhibit bacterial mat structures, stromatolites, fenestral structure, reef-building coral structures, mudcracks, crossbedding and other features of tidal environments. High-energy host rocks exhibit conglomerate- and sandstone-filled channels contain scour-and-fill, crossbedding, parallel lamination, mud rip-up clasts, and ripple marks.

Age Range

No Archean deposits are known. Age distribution of deposits can best be described by the quantity of copper metal deposited during different time periods as shown in the figure below.



The Upper Proterozoic rocks and, especially, Neoproterozoic rocks are the most productive. Permian rocks in Europe and Lower Carboniferous rocks in Central Asia are less important. Other small deposits are found throughout the Phanerozoic.

Depositional Environment

Highly permeable sediments in epicontinental shallow-marine basins near the paleo-equator. Sabkhas. High evaporation rate.

Tectonic Setting(s)

Favorable settings are intracontinental rifts, aulacogens, failed arms of triple junctions, and passive continental margins. Major graben and growth faults are commonly contemporaneous with mineralization.

Associated Deposit Types

Halite, sylvite, gypsum, anhydrite deposits occur in the same sedimentary sequences. Sandstone uranium, unconformity uranium, basalt copper, and Kipushi Cu-Pb-Zn deposits can occur in the same districts.

DEPOSIT DESCRIPTION

Mineralogy All deposits contain one or more of the following minerals deposited in zones in this order: chalcocite and other Cu_2S minerals, bornite, chalcopyrite, pyrite, and subordinate galena and sphalerite. Chalcocite forms near the oxidized source of copper; pyrite forms near the reduced rocks. Native copper occurs in deposits deficient in sulfide. Native silver is common. Some deposits in Zambia and Republic of Congo contain carrollite, Co-pyrite and Ge minerals.

Texture/Structure Minerals are finely disseminated, stratabound, locally stratiform. Framboidal or colloform pyrite is common. Cu minerals replace pyrite and cluster around carbonaceous clots or fragments.

Alteration Green, white, or gray rocks rich in Fe-calcite and chlorite result from reaction of reducing fluids with red beds. Oxidizing fluids produce albitic, hematite rocks depleted in base metals, calcium and potassium. Metamorphosed red beds may have a purple or violet color.

Ore Controls Reducing 1ow-pH environments such as marine black shale, fossil wood, algal mats are important as well as abundant biogenic sulfides and pyritic sediments. High permeability of footwall sediments is critical. Boundaries between hydrocarbon fluids or other reduced fluids and oxidized fluids in permeable sediments are common sites of ore deposition.

Weathering Surface exposures may be completely leached. Secondary chalcocite enrichment is not present in many deposits because of low pyrite abundance and corresponding lack of acidic waters.

Geochemical Signature Cu, Ag, Pb, Zn (Mo, V, U) (CO, Ge). Au is low. Weak radioactivity in some deposits.

Environmental Considerations The zonal distribution of sulfide minerals must be considered in evaluating the environmental factors involved in mining sediment-hosted copper deposits. Chalcocite and bornite in the high-grade zone are fairly stable minerals in the oxidizing environments in mines and mine dumps, and pyrite occurs only as trace amounts in this zone. In the low-grade zone, pyrite accompanies chalcopyrite and becomes increasingly abundant outward as copper grade decreases. This relationship should be used to guide mining plans where acid mine drainage caused by oxidizing pyrite must be avoided. Calcite is present in 20 deposits in the database and may be present in many more. The presence of calcite mitigates against the development of acid mine drainage.

The arsenic minerals tennantite, enargite, luzonite, and arsenopyrite are listed as minor or trace minerals in 10 deposits and occurrences in the database. Most of these 10 are important deposits that have received the attention of mineralogists. These are Mufulira, Republic of Congo; Mansfield, Germany; Graviisk, Russia, and Dzhezkazgan in Kazakstan. Five redbed occurrences in Permian and lower Triassic rocks in the Maritime Alps of France contain tennantite or enargite (Vinchon, 1984). These mineral occur with chalcopyrite as a late hydrothermal overprint on sedimentary–diagenetic bornite-chalcocite mineralization.

Arsenic, cadmium, mercury and nickel are listed in the descriptions of the geochemistry of Dezhkazgan and Graviisk. Mount Gunson, South Australia, contains anomalous arsenic (Knutson and others, 1983).

Genetic Overview

Sediment-hosted copper deposits are formed by fluid mixing in permeable sedimentary and (more rarely) volcanic rocks. Two fluids are involved: an oxidized brine carrying copper as a chloride complex, and a reduced fluid, commonly formed in the presence of anaerobic sulfate-reducing bacteria. For a sediment-hosted copper deposit to form, four conditions are required:

1. There must be an oxidized source rock. This rock must be hematite stable and must contain ferromagnesian minerals or mafic rock fragments from which copper can be leached. In Zambia erosion of an early formed porphyry copper deposit is thought to have contributed copper to the source rock (Wakefield, 1978). Typical source rocks are continental red sandstone, shale, conglomerate, and subaerial volcanic rocks. Marine volcanic rocks are unsuitable as source rocks because they have not degassed their volatile components. Contained reduced sulfur in marine volcanic rocks precludes the formation of a hematite-stable environment.

Leaching of copper from the source rock at moderately low pH may be described by equation 1.

(1) $$Cu_2O + 6\ Cl^- + 2\ H^+ = 2\ CuCl_3^{2-} + H_2O$$

2. Following equation 1, there must be a source of brine to mobilize copper. Evaporites are commonly intrerbedded with red beds and act as brine sources, but any sedimentary environment in which evaporation exceeds rainfall will produce brines. Brines may also form by evaporation of sea water where connection with the open sea is restricted as in rift valleys. The brines are generally rich in sodium because other cations, potassium, calcium, and magnesium, are removed during formation of clays, sulfates, and carbonates. Davidson (1965) directed attention to the coincidence of evaporite deposits with Phanerozoic stratabound sediment-hosted copper deposits in many parts of the world and proposed that brine derived from evaporites was the transporting medium for copper and other metals.

3. There must be a source of reduced fluid to precipitate copper and form a deposit. The chemistry of brine formation, and copper mobilization and precipitation was described by Rose (1976). Reduced fluids can be derived from organic-rich shales and carbonate rocks, from pockets of liquid or gaseous hydrocarbons in the host sediments or from any sedimentary fluid in equilibrium with pyrite. In equation 2 copper-rich brine contacts organic material and produces native copper.

(2) $$2\ CuCl_3^{2-} + 2\ H_2O + C = 2\ Cu^0 + 1\ CO_2 + 4\ H^+ + 6\ Cl^-$$

Note that HCl appears on the right of this equation and others below. This enables solution of carbonates and replacement of calcite cement by native copper.

Sulfide in the form of finely disseminated pyrite is commonly found in reduced host sediments. The amount of pyrite in typical black shale is insufficient to supply all of the sulfur in high-grade copper deposits. A more abundant source of sulfide is from reduction of sulfate by carbonaceous material, promoted by bacterial activity in the sediment (Sweeney and Binda, 1989) (equation 3).

(3) $$SO_4^{2-} + CH_4 = S^{2-} + CO_2 + 2H_2O$$

Reaction of chloride complex with sulfide produces chalcocite

(4) $$2\ CuCl_3^{2-} + S^{2-} = Cu_2S + 6\ Cl^-$$

Sulfate ion is commonly abundant in brines derived from evaporates and may accompany copper-rich oxidized solutions. Where this brine mixes with reduced fluids the following reaction describes the result..

(5) $$2\ CuCl_3^{2-} + SO_4^{2-} + CH_4 = Cu_2S + CO_2 + 2\ H_2O + 6\ Cl^-$$

Action of sulfate reducing bacteria is required to drive this reaction at near-surface temperatures.

4. There must be conditions favorable for fluid mixing. Haynes (1986) concluded that most sulfide ores are precipitated within 50 centimeters of the sediment-water interface because bacterial sulfate reduction below this depth is inhibited. Prelithification permeability in shale provides bedding-parallel sites for fluid mixing.

Fluid pressures derived from sediment compaction is important factor in fluid mixing, and deposits are most commonly situated at basin margins where mixing is most likely to take place.

Faulting or folding may produce a hydraulic head that causes one fluid to invade the site of another. Disruption of sedimentary sequences by salt intrusion can also promote fluid mixing (see Jowett, 1986; Ruan and others, 1991; Avila-Salinas, 1990).

A permeable host rock or other open space must be present in which the fluids can mix. Intergranular space in fine-grained sediments prior to compaction and

lithification is a common site for deposition. Solution cavities in carbonate rocks are less common depositional sites (MacKevett and others, 1997).
If any of these four conditions are not met, a deposit will not form, even in the most favorable rock environments.

The Database

The Geological Survey of Canada published a database of 950 deposits and occurrences of sediment-hosted stratiform copper deposits (Kirkham and others, 1994). From this file, 133 deposits with data on tonnage and metal grade were extracted and reserve and production data were combined to provide a single tonnage-grade estimate for each deposit for use in statistical modeling. For purposes of tonnage and grade modeling, a deposit is defined as one or more separate orebodies separated from its nearest neighbor by less than 2,000 m. The median tonnage of the whole set of deposits is 11 million metric tons (Mmt) and the mean copper grade is 1.7 wt percent. A silver grade is available for 37 of these and the upper ten percent of deposits contains 30 grams per metric ton. Cobalt grade of the upper ten percent is 0.2 wt percent based on data for 18 deposits. The distribution is log normal and tonnage and metal grades are independent.

Subtypes

Three subtypes of sediment-hosted copper deposits with significant differences in tonnage and copper grade are recognized: reduced-facies Cu, redbed Cu, and Revett Cu. The three types differ in the strength and efficiency of the reductant at the site of deposition. In reduced-facies deposits, the reductant is a marine or lacustrine fine-grained sediment containing abundant organic matter. In redbed deposits, the reductant is more weakly distributed, represented by patches of organic debris in sandstone. In Revett Cu deposits, the reductant is broad and diffuse and in some Phanerozoic deposits can be shown to be gaseous or liquid hyrocarbon, or sulfide-rich sour gas.

Median *tonnages* are 1.2 Mmt for 35 redbed deposits, and 33 Mmt for 58 reduced-facies deposits, and 14 Mmt for 11 Revett deposits. This difference between Redbed and reduced-facies is significant at the one percent level, and between Redbed and Revett at the one percent level (such a difference could happen by chance less than tone percent of the time).

Median copper *grades* are 1.7 percent for redbed deposits and 2.3 percent for reduced-facies deposits. This difference is significant the five percent level. Median copper grade for Revett Cu deposits 0.79 percent, and 10 percent of the deposits have a silver grade of 31 grams per ton.

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Model 30b.1

GRADE AND TONNAGE MODEL OF SEDIMENT-HOSTED Cu

By Dennis P. Cox and Donald A. Singer

(Replaces Model 30b of Mosier and others (1986)

COMMENTS: A deposit is defined as one or more separate orebodies separated from its nearest neighbor by more than 2,000 m.

DEPOSITS

Name	Country	Name	Country
Agoujgal	MRCO	Fungurume	ZIRE
Aitik	SWDN	Itawa	ZMBA
Al Mehdadah	SAAR	Jabal Murryyi	SAAR
Alaska	ZIMB	Jardin	CILE
Alderly Edge	UKEN	Jay	CNNT
Avaroa	BLVA	JF	USMT
Aynak	AFGH	Juaramento	AGTN
Bagacay	PLPN	June Creek	CNNT
Ballyvergin	UKIR	Kabolela	ZIRE
Barda González	AGTN	Kakanda	ZIRE
Big Indian	USUT	Kalengwa	ZMBA
Blinman	AUSA	Kamatanda	ZIRE
Boleo	MXCO	Kambove	ZIRE
Burra	AUSA	Kamfundwa	ZIRE
Bushman Group	BOTS	Kanmantoo	AUSA
Bwana Mkubwa	ZMBA	Kansanshi	ZMBA
Cachoeiras de Binga	ANGL	Kasaria	ZMBA
Caleta Coloso	CILE	Kilembe	UGND
Camaquã District	BRZL	Kimbwe	ZIRE
Canfield Dome	CNDA	Kinsenda	ZIRE
Cashin	USCO	Klein Aub	NAMB
Cerro dos Martíns	BRZL	Kolwezi	ZIRE
Cerro Granito	AGTN	Kona Dolomite	USMI
Chacarilla	BLVA	Konkola-Kirila Bombwe	ZMBA
Chambishi	ZMBA	Konrad	PLND
Chibuluma South	ZMBA	Ladderbjerg	GRLD
Chibuluma-Chibuluma West	ZMBA	LaoXue	CINA
Chifupu	ZMBA	Las Vigas	MXCO
Chimiwungo-Lumwana	ZMBA	Lisbon Valley	USUT
Chingola	ZMBA	Lochaber Lake	CNNS
Coates Lake	CNNT	Luanshya	ZMBA
Corocoro	BLVA	Luansobe	ZMBA
Creta	USOK	Lubin	PLND
Darband	AFGH	Lubwe	ZMBA
Dorchester	CNNS	Luishia	ZIRE
Dzhezkazgan	KAZN	Lukuni	ZIRE
Esmeralda	BLVA	Lupato	ZIRE
Etoile	ZIRE	Mallow	UKIR
Fenan	JRDN	Malundwe-Lumwana	ZMBA
FengShan	CINA	Mangula	ZIMB
Fitula	ZMBA	Mangum	USOK

Model 30b.1--Con.

Name	Country	Name	Country
Mansfeld	GRMY	Richelsdorf	GRMY
Marsberg	GRMY	Rock Creek	USMT
Martín Bronce	AGTN	Rubjerg Knude	GRLD
Matsitama	BOTS	San Bartolo	CILE
Menda Mendipe	ZIRE	San Romeleo	AGTN
Mimbula	ZMBA	Serra do Diamante	BRZL
Mindola-Nkana N-S	ZMBA	Sesa	ZIRE
Missoula National	USID	Shackleton	ZIMB
Mokambo	ZMBA	ShiShan	CINA
Mount Gunson	AUSA	ShiZhiShan	CINA
Mufulira	ZMBA	Scholle	USNM
Mufumbwe	ZMBA	Silverside	ZIMB
Mutoshi	ZIRE	Snowstorm	USID
Mwambashi	ZMBA	Spar Lake	USMT
Mwerkera	ZMBA	Stauber	USNM
Nacimiento	USNM	Talat n Ouamane	MRCO
Nchanga	ZMBA	TangDan	CINA
Ngwako Pan	BOTS	Tansrift	MRCO
Niagara	USID	Tenke	ZIRE
Nkana North Limb	ZMBA	Timna	ISRL
Norah	ZIMB	Turco	BLVA
Oamites	NAMB	Udokan	RUSA
Pedra Verde	BRZL	Uyuni	BLVA
Pitanda	ZMBA	Vermillion River	USMT
Pitanda South	ZMBA	White Pine	USMI
Presque Isle	USMI	Witvlei	NAMB
Repparfjord	NRWY	YinMin	CINA

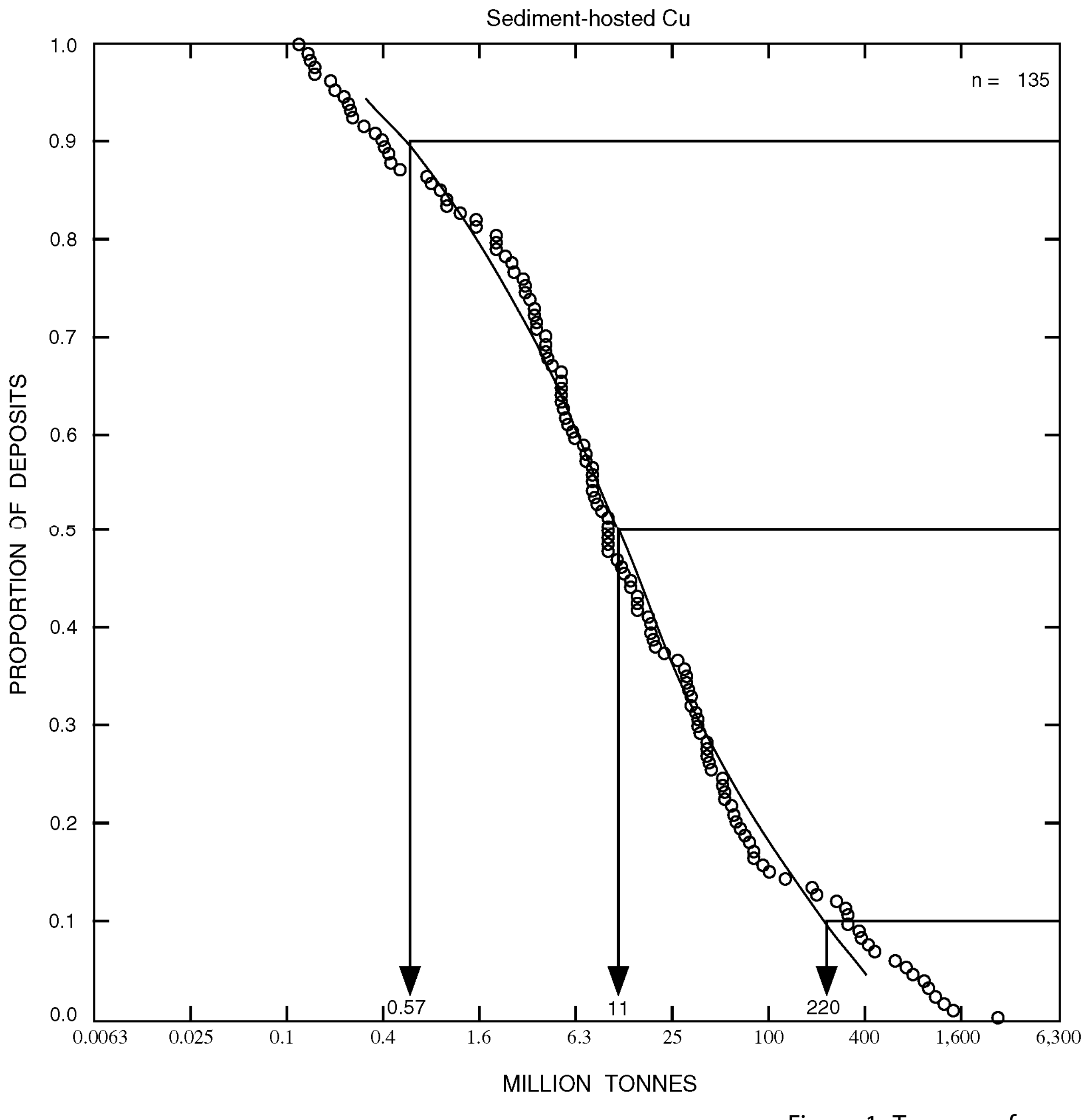


Figure 1. Tonages of sediment-hosted Cu deposits

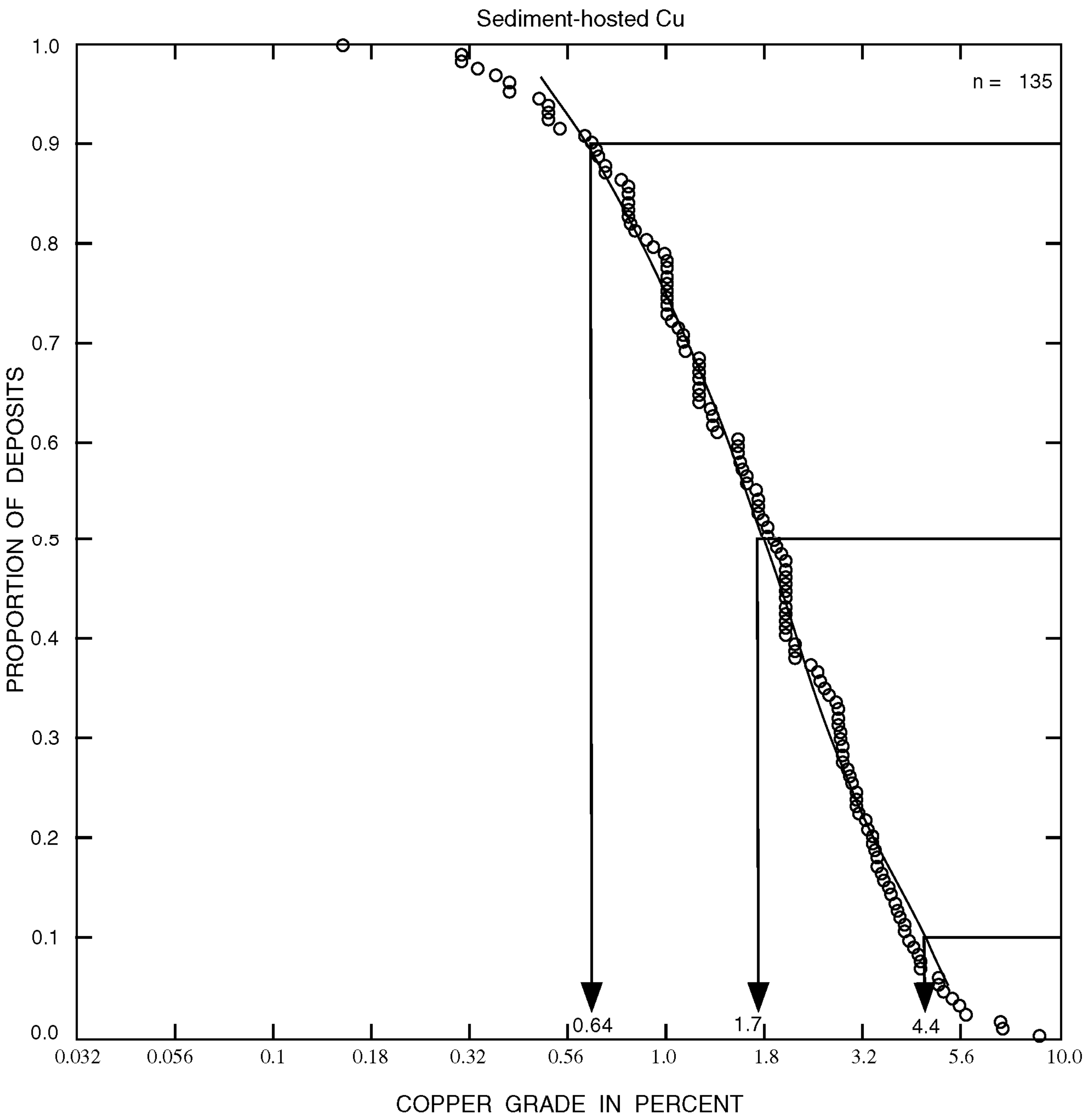


Figure 2. Copper grades of sediment-hosted Cu deposits.

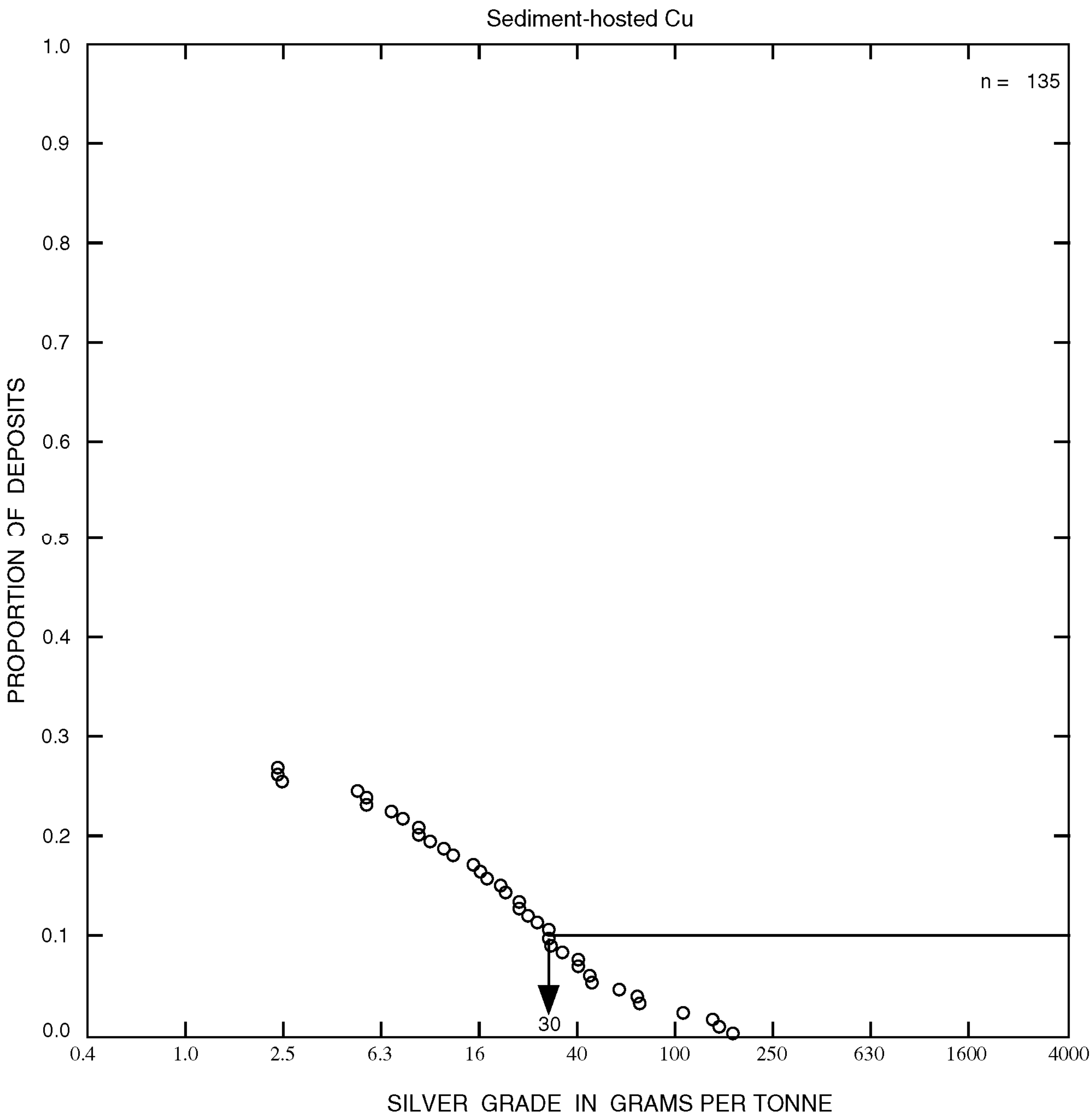


Figure 3. Silver grades of sediment-hosted Cu deposits.

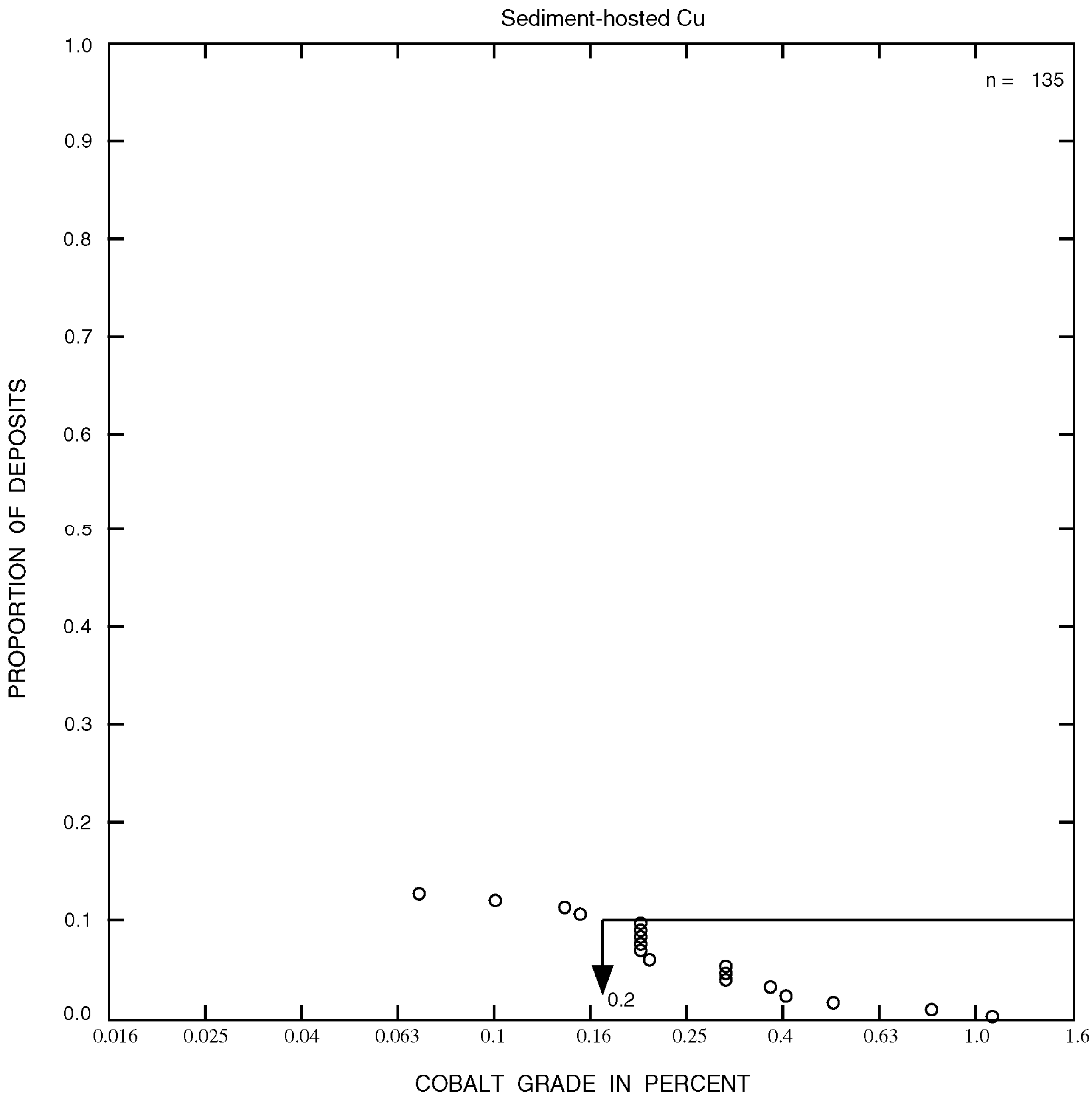


Figure 4. Cobalt grades of sediment-hosted Cu deposits.

DESCRIPTIVE MODEL OF REDUCED-FACIES SUBTYPE

MODEL 30b.2, (Replaces Sediment-hosted Copper, 30b, Cox, 1986)

By Dennis P. Cox

APPROXIMATE SYNONYMS Copper-shale (Lindsey, 1982); stratiform copper hosted by low-energy sediments (Haynes, 1986a); marine paralic (Kirkham, 1994); Kupferschiefer type (Kirkham, 1989); Central African type.

DESCRIPTION Stratabound, disseminated copper sulfide deposits in reduced-facies sedimentary rocks that overlie, or are interbedded with, red-bed sequences or subaerial basalt flows. Copper is mobilized by oxidized brines in redbeds; sulfide-bearing fluids are derived from reduction of sulfate in marine or lacustrine sediments. Subsequent tectonism causes fluid mixing and sulfide deposition.

GENERAL REFERENCES Gustafson and Williams (1981), Lur'ye (1986), Kirkham (1989), Sweeney and others (1991).

GEOLOGICAL ENVIRONMENT

Rock Types Host rocks are reduced facies marine or lacustrine rocks such as green, black, or gray shale, siltstone, thinly laminated tidal facies, or reefoid carbonate rocks, and dolomitic shales. Fine-grained clastic rocks and carbonates host 69 percent of deposits and occurrences (Table 1). Organic carbon and finely disseminated pyrite are common constituents. Host rocks for 16 percent of the occurrences are described as carbonaceous, bituminous, algal or stromatolitic.

Deposit Type	Number of deposits and occurrences	Sandstone, quartzite, arkose, conglomerate	Siltstone, shale, clay mudstone,	Limestone, dolomite, marl	Schist, phyllite, amphibolite, marble
Reduced facies	100	29	41	28	2
Redbed	155	85	12	2.5	<1
Revett	31	77	22	0	0
Unclassified	102	30	20	25	25

Table 1. Host rocks of mineralization for individual occurrences by type expressed in percent of occurrences having a host rock description).

These host rocks overlie, or are interbedded with redbed sequences containing red to brown or purple hematite-bearing sandstones siltstones and conglomerate of continental deltaic, fluviatile, or aeolian origin (tables 2 and 3). Mafic dikes and sills formed during rifting are present locally. Thick, subaerial basalt flows are important as sources of copper in a few deposits. Evaporite beds are important as a source of brine for many deposits (tables 2 and 3). In metamorphosed sequences, missing intervals in the stratigraphic section are evidence for original evaporites.

According to the Sediment-Hosted Copper database, reduced facies deposits are underlain by a variety of rock types dominated by sandstone and conglomerate (table 2).

Deposit subtype	Sandstone, quartzite, arkose,	Conglom-erate	Siltstone, shale, clay mudstone,	Limestone, dolomite, marl	Evapor-ite	Mafic lava
Reduced facies	49	12	11	15	8	4
Redbed	39	26	13	8	0	13

Table 2. Rocks underlying mineralization for individual occurrences by type expressed in percent of occurrences having a description of the underlying rock (47 reduced facies and 26 redbed).

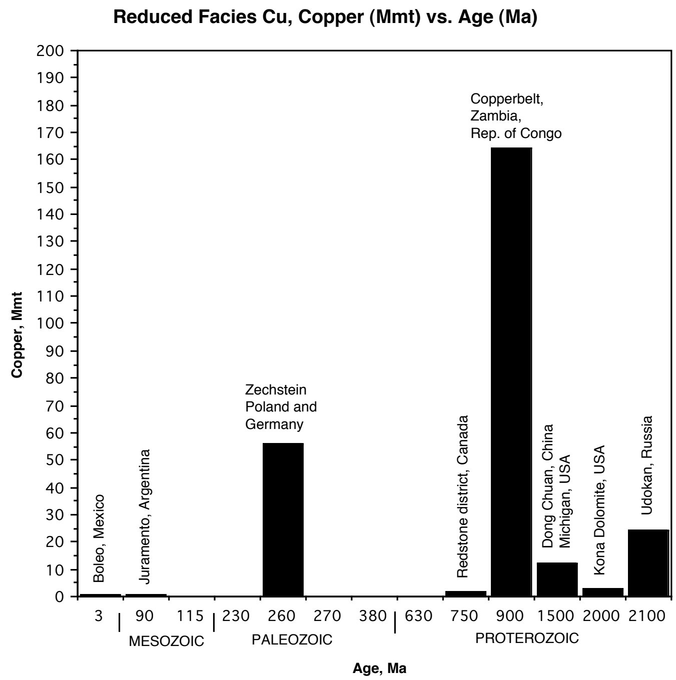
Reduced facies deposits in the database are most commonly overlain by carbonates, but sandstone, shale and evaporates are locally important (table 3).

Deposit subtype	Sandstone, quartzite, arkose, conglomerate	Siltstone, shale, clay mudstone,	Limestone, dolomite, marl	Evaporite, gypsum
Reduced facies	27	20	42	10

Table 3. Rocks overlying mineralization for individual occurrences by type expressed in percent of 40 occurrences having a description of the overlying rock.

<u>Textures</u> Reduced facies rocks are thin-bedded to finely laminated and exhibit bacterial mat structures, stromatolites, fenestral structure, reef-building coral structures, mudcracks, crossbedding and other features of tidal environments.

<u>Age Range</u> Deposits are restricted to periods of Earth history in which the atmosphere was oxygenated. Udokan in Russia is Lower Proterozoic (Bolodin and others, 1994). Most deposits favor Middle and Late Proterozoic rocks worldwide. Permian rocks host major deposits in Germany and Poland, Permian and early Mesozoic rocks in Eastern Europe and USA. All ages from Lower Proterozoic are possible. The figure below shows the estimated amount of copper deposited during Earth history. The numbers in the horizontal scale represent ages of the major deposits shown in the histogram.



Depositional Environment Deposits form in continental clastic sedimentary basins succeeded by epicontinental shallow-marine or lacustrine basin within 30° of the paleo-equator. Sabkhas, evaporites, or other sources of brines are important. Most deposits form during transgression of reduced marine sediments over redbed deposits (Brown and Chartrand, 1986). In the terminology of sequence stratigraphy, deposits are in condensed stratigraphic sections resulting from maximum flooding (Ruffell and others, 1998). In Zambia ores are found along the paleoshoreline (Fleischer and others, 1976). Deposits are zoned from chalcocite to bornite to chalcopyrite to pyrite away from the shoreline toward anoxic deep water. According to Haynes (1986a), most deposits are formed less than 50 cm below the sediment water interface because bacterial reduction of sulfate is inhibited below that depth. Deposits commonly have a mineral zonation from chalcocite to bornite to chalcopyrite to pyrite upward from the contact of host rocks with underlying redbeds.

The occurrence in Zambia of sulfide grains in foreset beds and in troughs of ripple marks suggests that some sulfide precipitation may take place above the water-sediment surface (Fleischer and others, 1976). Garlick (1989) presented evidence from the Copperbelt for transport of copper by surficial brines flowing across sabkha deposits and into anoxic marine waters trapped behind algal reefs. The high density of the brines would cause rapid mixing with bottom water and precipitation of copper sulfides. These sulfides plus detrital quartz and clays would descend to the sea floor and form the ore beds.

Many of the most important sediment-hosted copper deposits were formed during the Neoproterozoic when most of the world's continental masses were joined in the Rodinia supercontinent. The presence of diamictites with striated clasts and scoured basal pavements suggest that two or more periods of continental glaciation occurred in the Neoproterozoic. These diamictite layers are overlain by thick deposits of carbonate rocks. Sediment-hosted copper deposits, where present, are below the diamictite layers, and were apparently formed during warm periods preceding glaciation. Thus Neoproterozoic sequences in which diamictites occur near the base of the section are probably not permissive for sediment-hosted copper deposits.

Tectonic Setting(s) An intracontinental rift or aulacogen with restricted marine circulation, succeeded by widespread euxinic marine deposits is the ideal setting for these deposits. Salt diapirism, major growth faults, thinning of sedimentary units, and unconformities may focus fluid flow and influence localization of deposits.

Lefebvre (1989) noted the importance of normal faulting in southern Shaba, Republic of Congo. He believes that hydrothermal solutions emanating from these faults were a major source of copper and cobalt in the sediments.

Associated Deposit Types Halite, sylvite, gypsum, and anhydrite deposits and redbed Cu deposits are formed contemporaneously. Unconformity-related uranium, and Kipushi Cu-Pb-Zn occur in overlying carbonate rocks in Southern Africa. Deposits of lead and zinc at Lubin in Poland are similar to sandstone lead deposits, but should be considered as distal parts of the reduced facies model.

DEPOSIT DESCRIPTION

Mineralogy Chalcocite and other Cu_2S-CuS minerals + bornite are the diagnostic minerals. Deposits may be zoned with centers of chalcocite-bornite, outer zones of chalcopyrite-pyrite, and peripheral galena-sphalerite. Some deposits contain carrollite and Co-pyrite commonly in the chalcopyrite-pyrite zone, and Ge minerals in the chalcocite-bornite zone.

Carbon-rich materials (bitumens, graphite, coal), although they are important components of favorable host rocks, are rarely found in copper ores. They are consumed by the redox reactions responsible for ore deposition.

Copper minerals can be arranged according to decreasing oxidation state as follows:

Mineral	**Formula**	**Oxidation state**
Chalcopyrite	$Cu\ Fe\ S_2$	all Cu^{++}
Covellite	Cu S	all Cu^{++}
Bornite	$Cu_5\ Fe\ S_4$	$Cu^{++}: Cu^{+} = 1 : 2$
Anilite	$Cu_7\ S_4$	$Cu^{++}: Cu^{+} = 1 : 3$
Digenite	$Cu_9\ S_5$	$Cu^{++}: Cu^{+} = 1 : 4$
Djurleite	$Cu_{31}\ S_{16}$	$Cu^{++}: Cu^{+} = 1 : 15$
Chalcocite	$Cu_2\ S$	all Cu^{+}
Native Copper	Cu	all Cu^{0}

Table 4 Copper minerals arranged by copper oxidation state

These minerals commonly form in zones with chalcocite deposited closest to the interface between brine and reduced fluid (Ripley and others, 1985). Covellite occurs in the transition zone between oxidized and reduced sediments. Pyrite occurs outside of the chalcopyrite zone. Cobalt, common in the African Copperbelt, is most abundant in the chalcopyrite zone, and galena and sphalerite in the Kupferschiefer of Poland mainly occur with pyrite (Oszczepalski, 1999).

The presence of cobalt, silver, lead and zinc in some deposits and not in others suggests that sedimentary exhalative processes may be important (Brown, 1984). High temperature deep basinal fluids introduced through basin-margin faults may overprint or mix with copper-rich brines to produce copper deposits with valuable byproducts.

Table 5 describes the occurrence of the most common minerals in each of the three deposit subtypes. Chalcocite is the most abundant mineral in 44 percent of the reduced facies occurrences described. Chalcopyrite is listed as most abundant in 17 percent of the occurrences.

Deposit subtype	Chalcocite, digenite, djurleite	Bornite	Chalcopyrite	Galena	Sphalerite	Pyrite
Reduced facies	82	61	72	8	6	30
Redbed	58	30	34	3	3	28

Table 5. Minerals present in individual occurrences by type expressed in percent of occurrences having a mineralogy description (57 reduced facies, 71 redbed).

<u>Texture/Structure</u> Finely disseminated, strata-bound, locally stratiform sulfides. Framboidal or colloform pyrite is commonly replaced by copper sulfides. Cu_2S-CuS minerals replace bornite which replaces chalcopyrite which replaces pyrite. Sulfides cluster around fossils, carbonaceous clots or fragments. Quartz in some ores contains fluid inclusions with NaCl, KCl, and rarely $BaCl_2$ daughter minerals.

<u>Alteration</u> Dolomitization is common in carbonate host-rocks. Regionally metamorphosed red beds are purple in color and contain Mg chlorite derived from basinal brines. Red sediments are bleached to greenish gray or light gray where they have been in contact with reduced fluids. In Zambia host shale and siltstone contain 5 to 10 percent K_20 and variable MgO up to 10 percent. These anomalous compositions are believed to result from diagenetic introduction of K-feldspar and chlorite (Moine and others, 1986)

<u>Ore Controls</u> Reducing environment such as pyritic black shales, algal mats or reef colonies are important ore controls. Sources of biogenic sulfide are also important. High permeability of footwall sediments is critical. The lowermost beds of transgressive reduced sediments, in contact with redbeds, are the most common loci of mineralization. In some deposits copper minerals are concentrated in sandstone beds that directly underlie the reduced-facies sediments (Oszczepalski and Rydzewsky, 1991). Rarely, as at Kennecott, Alaska, sulfides are hosted by fissures or karst breccias in organic rich carbonate rocks (MacKevett and others, 1997). Most important is the late orogenic development of fracture-permeability and hydrologic head to drive the process of fluid mixing.

Weathering Malachite and azurite are common in outcrops, but in some permeable rocks, surface exposures may be completely leached. Secondary chalcocite enrichment down dip is present in some deposits but is uncommon because of low pyrite content and low acid production during weathering.

Geochemical Signature Cu, Ag, Pb, Zn (Mo, Re, V, U) (Co, Ge). Au is low. Weak radioactivity is noted in some deposits. In the African Copperbelt treeless areas called "copper clearings," in which soil is copper-rich, occur over deposits (Hawkes and Webb, 1962; Reilly, 1967). These areas may contain copper-tolerant and copper-accumulating plants called "copper flowers" (Maisse and others, 1978; Reilly, 1967). Yellow leaf color (chlorosis), even among copper accumulating plants, is also common in copper clearings,.

EXAMPLES

Kupferschiefer, PLND	(Oszczepalski, 1999)
Zambia deposits	(Annels, 1989)
Kamoto, ZIRE	(Bartholome and others, 1976)
Redstone, CNNT	(Chartrand and others, 1989)
Dongchuan, CINA	(Ruan and others, 1991)

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Model 30b.2

GRADE AND TONNAGE MODEL OF REDUCED FACIES Cu

By Dennis P. Cox and Donald A. Singer

(Replaces Model 30b of Mosier and others (1986)

COMMENTS: A deposit is defined as one or more separate orebodies separated from its nearest neighbor by more than 2,000 m. The copper grade distribution is significantly different from lognormal because of the inclusion of two low-grade deposits from Nova Scotia, Canada, and Michigan, USA.

DEPOSITS

Name	Country	Name	Country
Boleo	MXCO	Lochaber Lake	CNNS
Bwana Mkubwa	ZMBA	Luanshya	ZMBA
Cachoeiras de Binga	ANGL	Lubin	PLND
Chambishi	ZMBA	Luishia	ZIRE
Chibuluma South	ZMBA	Lukuni	ZIRE
Chibuluma-Chibuluma West	ZMBA	Lupato	ZIRE
Chingola	ZMBA	Mangum	USOK
Coates Lake	CNNT	Mansfeld	GRMY
Creta	USOK	Mimbula	ZMBA
Etoile	ZIRE	Mindola-Nkana N-S	ZMBA
FengShan	CINA	Mokambo	ZMBA
Fitula	ZMBA	Mount Gunson	AUSA
Fungurume	ZIRE	Mufulira	ZMBA
Jay	CNNT	Mutoshi	ZIRE
Juaramento	AGTN	Nchanga	ZMBA
June Creek	CNNT	Oamites	NAMB
Kabolela	ZIRE	Presque Isle	USMI
Kakanda	ZIRE	Richelsdorf	GRMY
Kamatanda	ZIRE	Sesa	ZIRE
Kambove	ZIRE	ShiShan	CINA
Kamfundwa	ZIRE	ShiZhiShan	CINA
Kimbwe	ZIRE	Talat n Ouamane	MRCO
Kinsenda	ZIRE	TangDan	CINA
Klein Aub	NAMB	Tenke	ZIRE
Kolwezi	ZIRE	Udokan	RUSA
Konkola-Kirila Bombwe	ZMBA	White Pine	USMI
Kona Dolomite	USMI	Witvlei	NAMB
Konrad	PLND	YinMin	CINA
LaoXue	CINA		

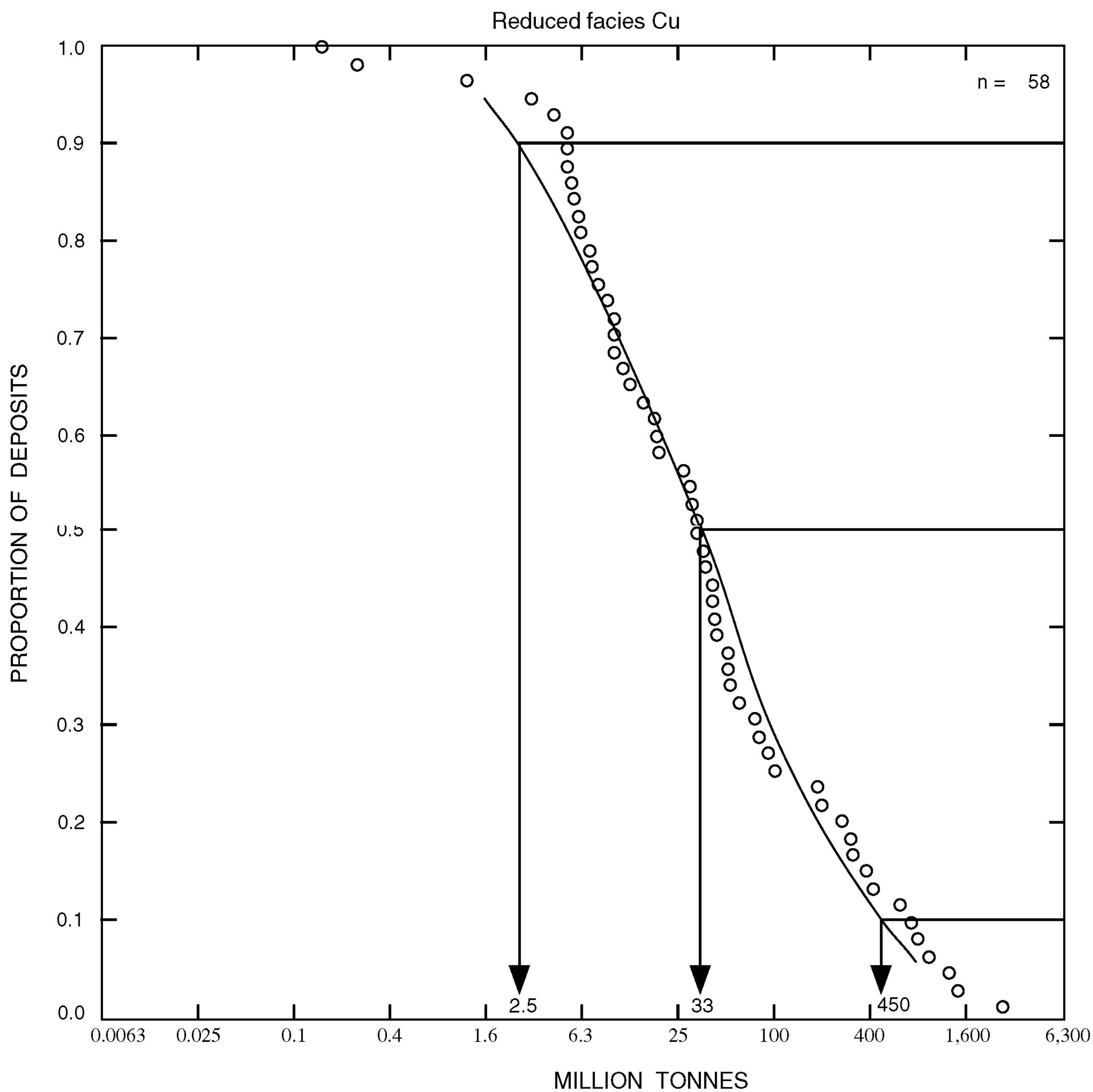


Figure 1. Tonnages of reduced facies Cu deposits.

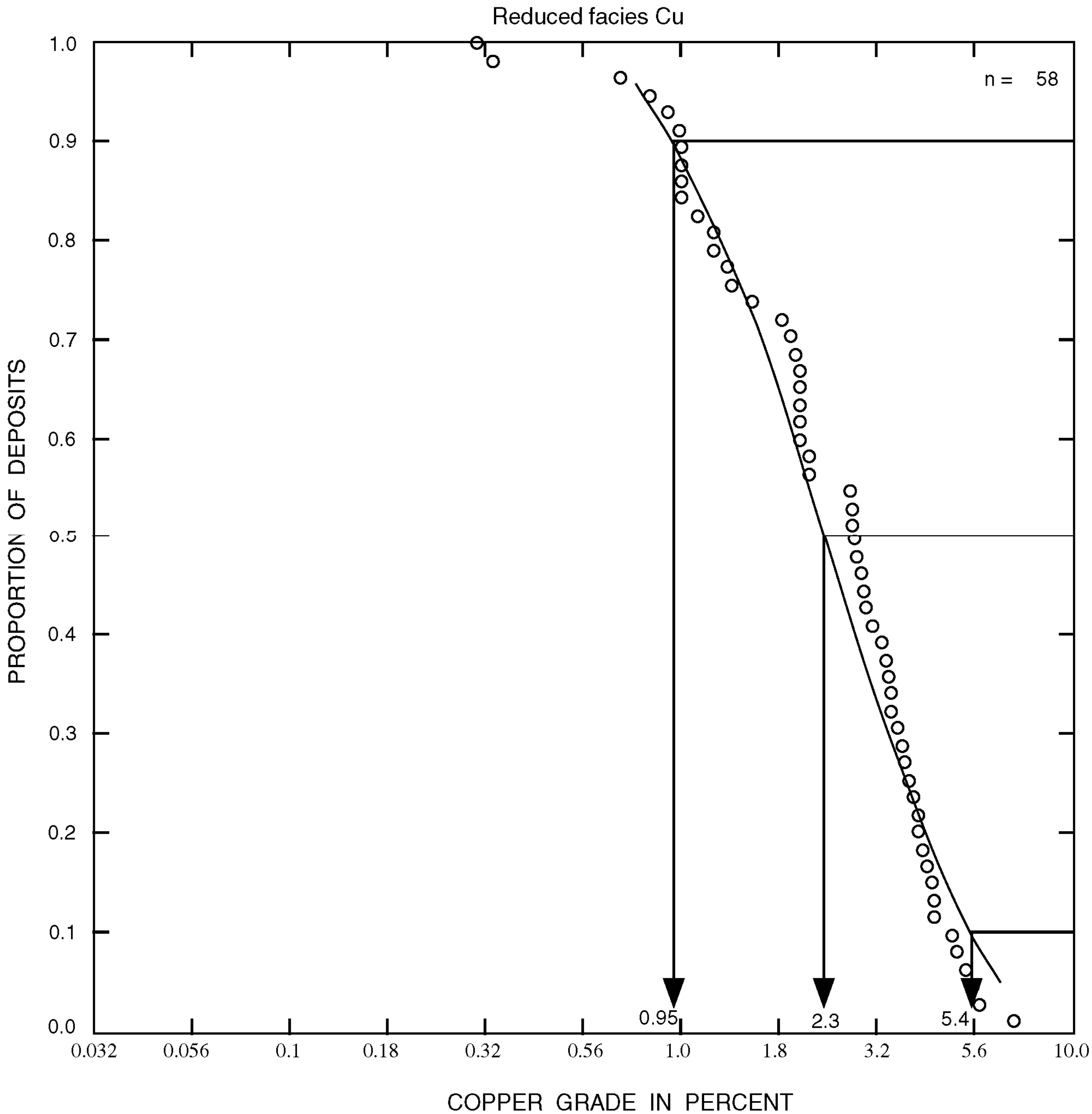


Figure 2. Copper grades of reduced facies Cu deposits.

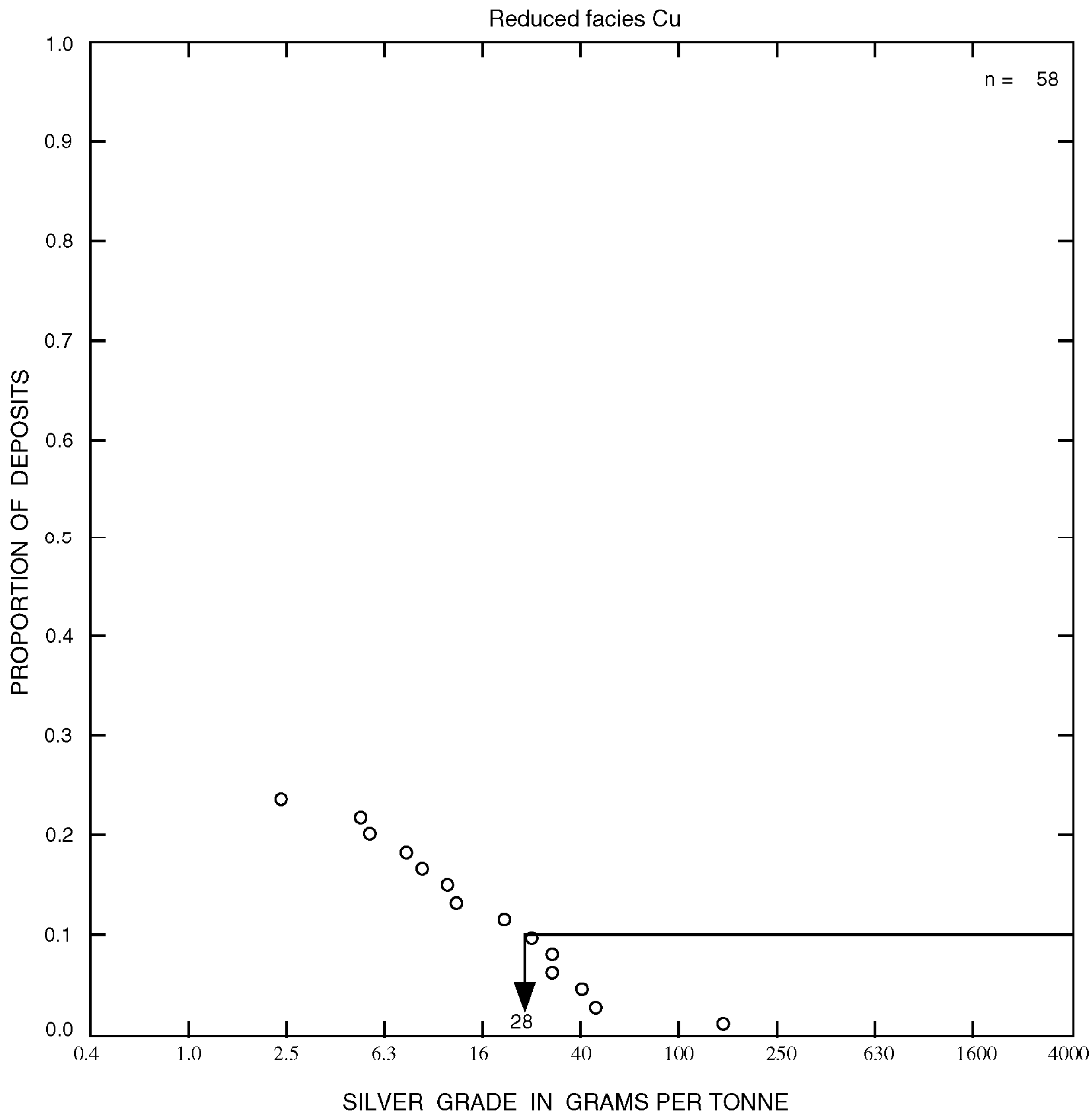


Figure 3. Silver grades of reduced facies Cu deposits.

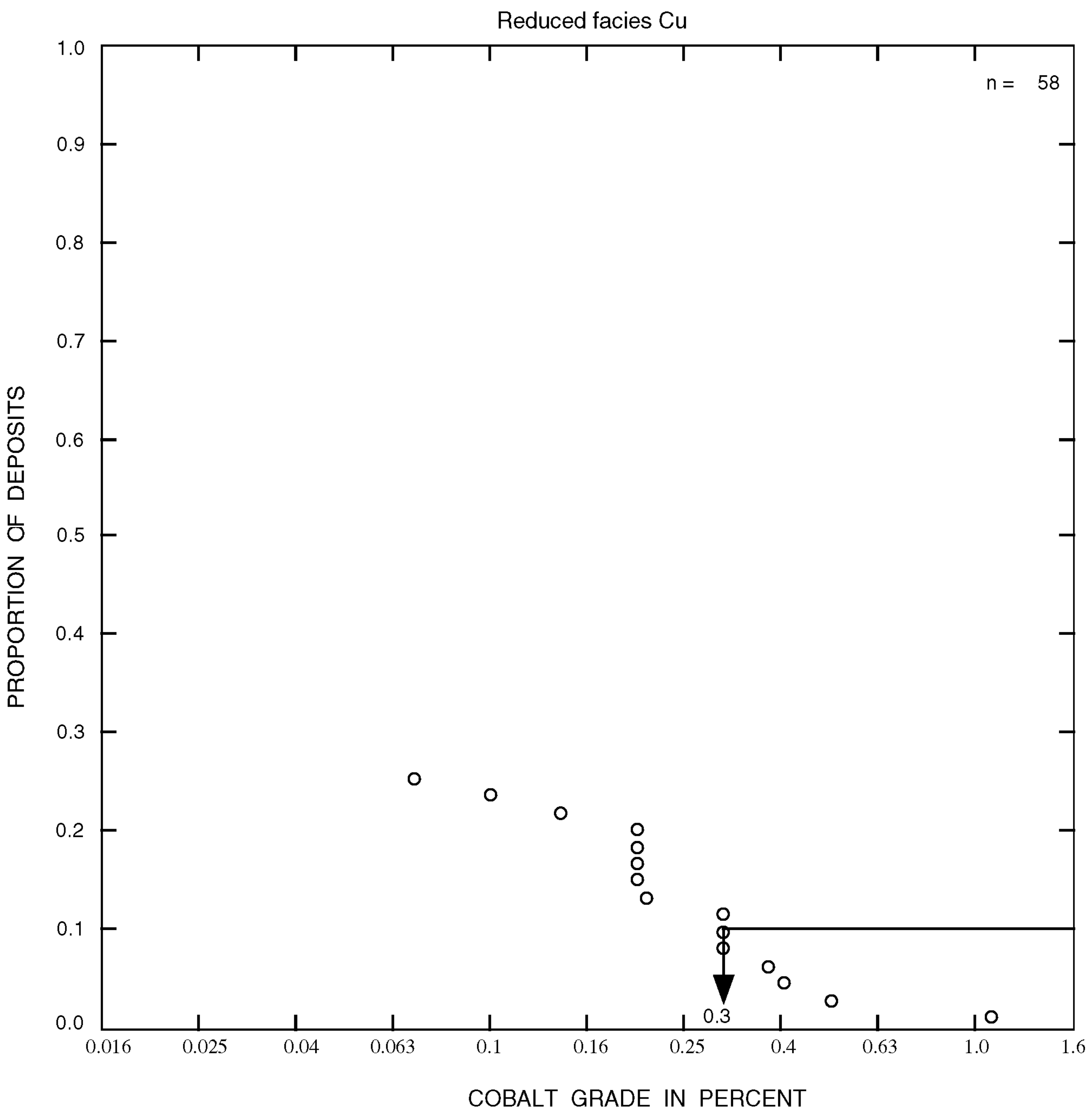


Figure 4. Cobalt grades of reduced facies Cu deposits.

DESCRIPTIVE MODEL OF REDBED CU 30b.3, (Replaces Sediment-hosted Copper, 30b, Cox, 1986)

By David A. Lindsey and Dennis P. Cox

APPROXIMATE SYNONYMS Redbed-hosted Cu, sandstone-hosted Cu, Continental redbed (Kirkham and others, 1994)

DESCRIPTION Redbed copper deposits are stratabound mineralized bodies of disseminated copper and copper sulfides, with or without silver, uranium and vanadium, occurring in reduced zones of red-bed sequences.

GENERAL REFERENCES Gustafson and Williams (1981), Eugster (1989), and Kirkham (1989).

GEOLOGICAL ENVIRONMENT

Rock Types The characteristic stratigraphic setting for redbed copper deposits is a redbed sequence containing white or gray bleached zones in sandstone and/or black, grey, or green (reduced) beds of shale and siltstone. In Devonian and younger rocks, host beds commonly contain fossil plant debris. Local evaporite beds are present in some cases, but not in others. Reducing traps formed by plant debris are of limited lateral extent; thus redbed copper deposits are generally small (Eugster, 1989).

According to the Sediment-Hosted Copper Database, 85 percent of Redbed deposits and occurrences are hosted by sandstone or conglomerate. Note the contrast with reduced facies Cu deposits mainly hosted in fine-grained, low energy clastic rocks and carbonates (table 1).

Deposit Type	Number of deposits and occurrences	Sandstone, quartzite, arkose, conglomerate	Siltstone, shale, clay mudstone,	Limestone, dolomite, marl	Schist, phyllite, amphibolite, marble
Redbed	155	85	12	2.5	<1
Reduced facies	100	29	41	28	2
Revett	31	77	22	0	<1
Unclassified	102	30	20	25	25

Table 1. Host rocks of mineralization for individual occurrences by type expressed in percent of occurrences having a host rock description (100 reduced facies, 155 redbed, 31 Revett, and 102 unclassified).

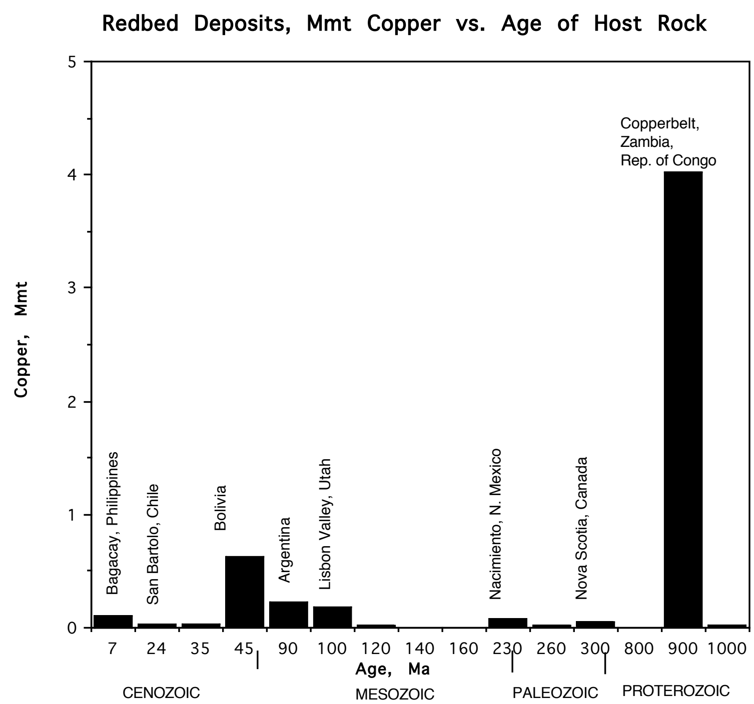
Redbed deposits are most commonly underlain by sandstone and conglomerate beds (table 2)

Deposit subtype	Sandstone, quartzite, arkose,	Conglom-erate	Siltstone, shale, clay mudstone,	Limestone, dolomite, marl	Evaporite	Mafic lava
Redbed	39	26	13	8		13
Reduced facies	49	12	11	15	8	4

Table 2. Rocks underlying mineralization for individual occurrences by type expressed in percent of occurrences having a description of the underlying rock (47 reduced facies and 26 redbed).

Textures Conglomerate- and sandstone-filled channels contain scour-and-fill, crossbedding, parallel lamination, mud rip-up clasts, and ripple marks. Siltstone and mudstone overbank deposits contain ripple marks, mud cracks, rootlet casts, and paleocaliche horizons.

Age Range No Archean deposits are known. The 4 Mmt of copper in Proterozoic deposits are in the footwall sandstones of the Copperbelt of Zambia. These deposits are in red sandstones that underlie the large reduced facies deposits and are termed the footwall ore bodies. Many deposits are known in Paleozoic, Mesozoic, and Cenozoic rocks (see figure below).



Depositional Environment Most host rocks were deposited within 30 degrees of the paleoequator (Kirkham, 1989). They were deposited by alluvial systems ranging from fans to meandering streams, commonly entering closed-basin playas or a variety of coastal environments, shallow epicontinental seas, and related evaporite basins. Sediments deposited in these environments are favorable hosts for oxidizing, saline fluids capable of leaching and transporting copper.

Tectonic Setting Redbed copper deposits occur in fault-bounded basins in various settings, including rifts, intermontane basins in broad zones of extension, and foreland molasse basins. Salt diapirism was important at Corocoro (Avila-Salinas, 1990; Cox and others, 1991).

Associated Deposit Types Sandstone (roll-front and tabular) uranium-vanadium, sandstone lead, reduced facies Cu, and evaporites may all be associated at various scales.

DEPOSIT DESCRIPTION

Mineralogy Principal minerals are chalcocite and other Cu_2S minerals, pyrite, bornite, and native silver. Native copper is the dominant mineral in environments depleted in sulfur. Bitumins and oil residues may indicate the passage of fluid hydrocarbons. Copper sulfide replacement of early pyrite and carbonaceous plant debris is common in New Mexico deposits (Woodward and others, 1974). If present, uranium may also be concentrated in carbonaceous matter. Metal sulfide zoning ranges from grain to deposit scale, reflecting directions of fluid flow and/or chemical gradients. Typical zonation of Cu_2S minerals, bornite, chalcopyrite, pyrite, galena, and sphalerite reflects the relative solubility products of these sulfides. The stability of copper and iron sulfide minerals in this zonation can also be understood in the system fO_2/fS_2 at equilibrium, with sulfate (barite or gypsum) supplying sulfur for sulfide precipitation (Sverjensky, 1989). If redox sulfur disequilibrium occurs, fluids may react with organic matter to precipitate native copper. Deposit zoning is not evident in all examples.

According to the Sediment-Hosted Copper Database, chalcocite is listed as the most abundant mineral 58 percent of the time. Table 3

Deposit subtype	Chalcocite, digenite, djurleite	Bornite	Chalco-pyrite	Galena	Sphalerite	Pyrite	Native copper
Redbed	58	30	34	3	3	28	14
Reduced facies	82	61	72	8	6	30	2

Table 3. Minerals present in individual occurrences by type expressed in percent of occurrences having a mineralogy description (57 reduced facies, 71 redbed). Data from Cox and others (2003).

Texture/Structure Ore minerals are disseminated as late cement in lenticular, elongate bodies. Mineralized replacement features may follow lamination and other sedimentary structures. Copper sulfides and native copper replace sandstone matrix, cement, and in some deposits, fossil plant

debris and pyrite. Ore minerals embay and corrode detrital grains and gangue cement. Vein fillings that cross-cut earlier structures represent late-stage remobilization, after the main mineralizing event.
Alteration Host beds are bleached white or gray; reduction spots and halos are common, especially around plant debris. Hematite and clay minerals are replaced by chlorite and ferroan calcite. Detrital and early diagenetic minerals are dissolved and replaced by ore minerals (Flint, 1989).
Ore Controls Permeable sandstone beds are major controls, as for example at the Nacimiento deposit in New Mexico (Woodward and others, 1974). Copper sulfides form locally around reductants such as plant debris and more broadly around concentrations of fluid hydrocarbons. Pyrite is a significant local reductant if abundant. Redox fronts (roll fronts) in ore-forming fluids and disequilibrium conditions are important chemical controls (Flint, 1989; Kirkham, 1989; Sverjensky, 1989).
Weathering Surface exposures of sulfides weather to hydroxides and carbonates, and may even be leached completely. Downdip and away from outcrop, supergene alteration and enrichment in chalcocite may occur.
Geochemical Signature Cu, Ag, Pb, Zn, (Mo, V, U). Some deposits weakly radioactive. Zambian redbed deposits contain Co.

EXAMPLES

Corocoro, BLVA	(Avila-Salinas, 1990; Flint, 1989)
Nacimiento, USNM	(Woodward and others, 1974)
Stauber, USNM	(Stauber, 1930)

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Model 30b.2

GRADE AND TONNAGE MODEL OF REDBED Cu

By Dennis P. Cox and Donald A. Singer

(Replaces Model 30b of Mosier and others (1986)

COMMENTS: A deposit is defined as one or more separate orebodies separated from its nearest neighbor by more than 2,000 m.

DEPOSITS

Name	Country	Name	Country
Avaroa	BLVA	Mwerkera	ZMBA
Bagacay	PLPN	Nacimiento	USNM
Barda González	AGTN	Ngwako Pan	BOTS
Canfield Creek	CNDA	Nkana North Limb	ZMBA
Cerro Granito	AGTN	Pitanda	ZMBA
Chacarilla	BLVA	Pitanda South	ZMBA
Chifupu	ZMBA	Rubjerg Knude	GRLD
Corocoro	BLVA	San Bartolo	CILE
Dorchester	CNNS	San Romeleo	AGTN
Esmeralda	BLVA	Scholle	USMN
Itawa	ZMBA	Sevaruyo	BLVA
Jabal Murryyi	SAAR	Stauber	USNM
Kasaria	ZMBA	Tansrift	MRCO
Ladderbjerg	GRLD	Turco	BLVA
Luansobe	ZMBA	Uyuni	BLVA
Martín Bronce	AGTN	Wadi Yiba	SAAR
Mwambashi	ZMBA		

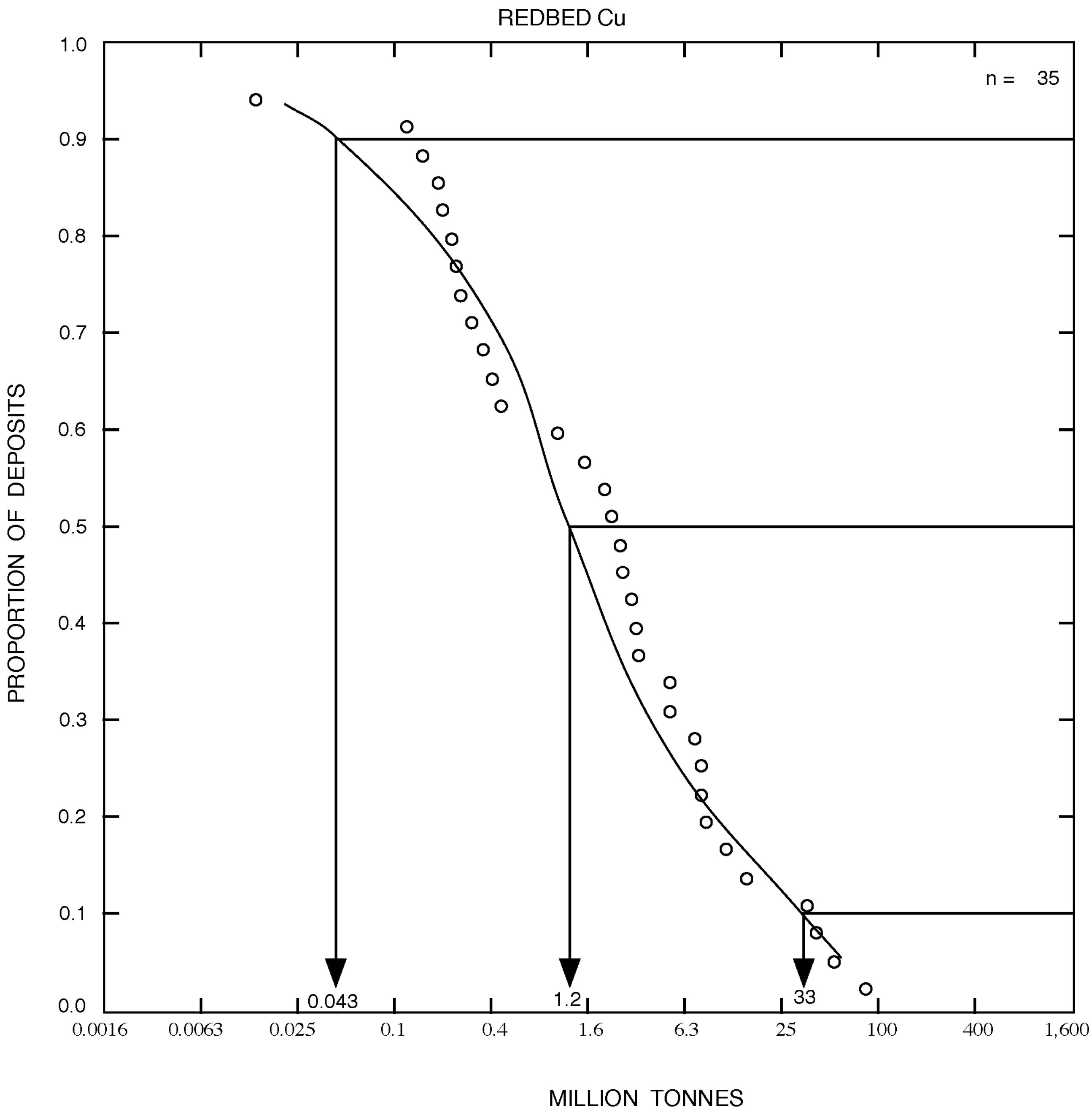

Figure 1. Tonnages of redbed Cu deposits.

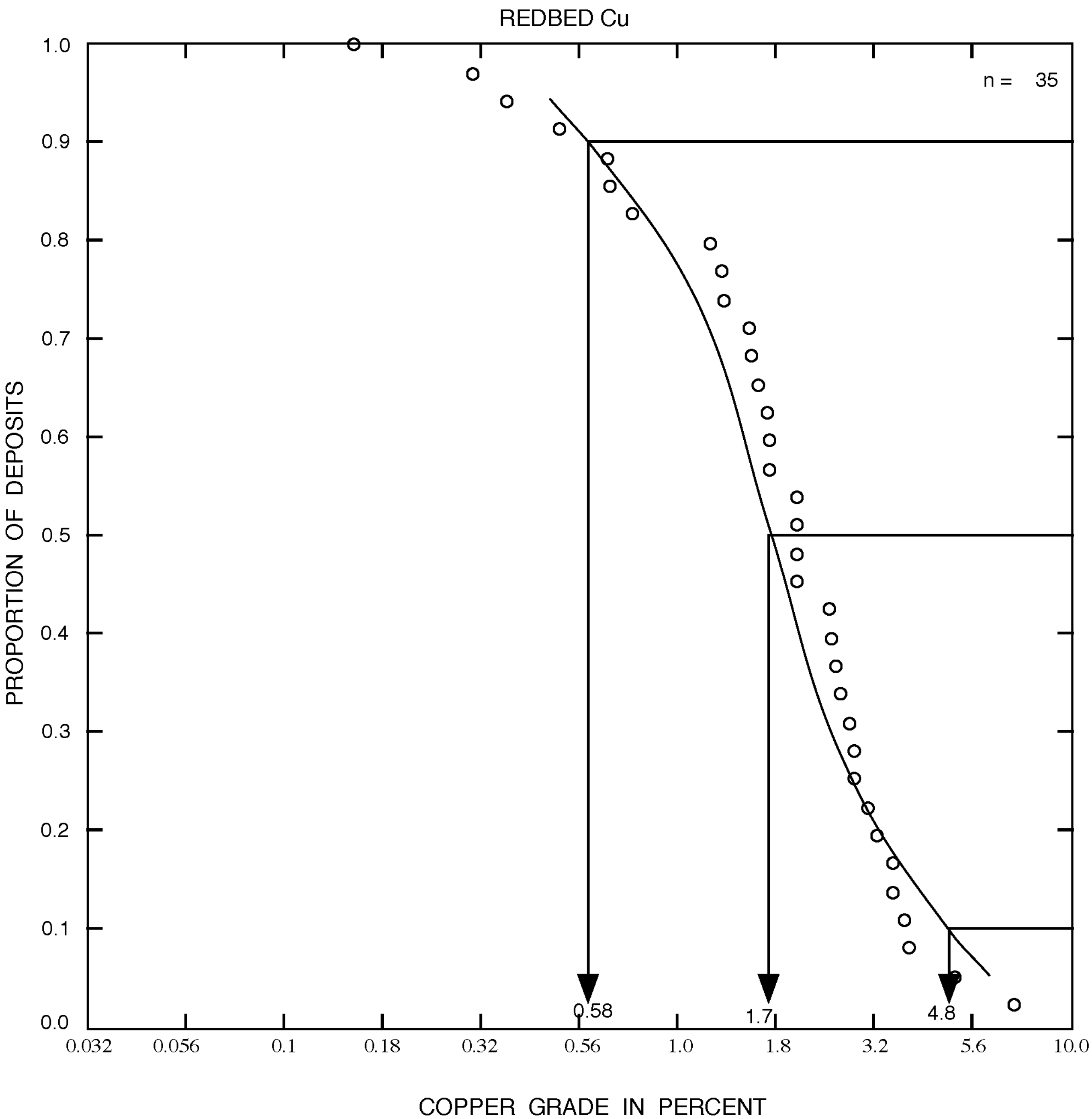

Figure 2. Copper grades of redbed Cu deposits.

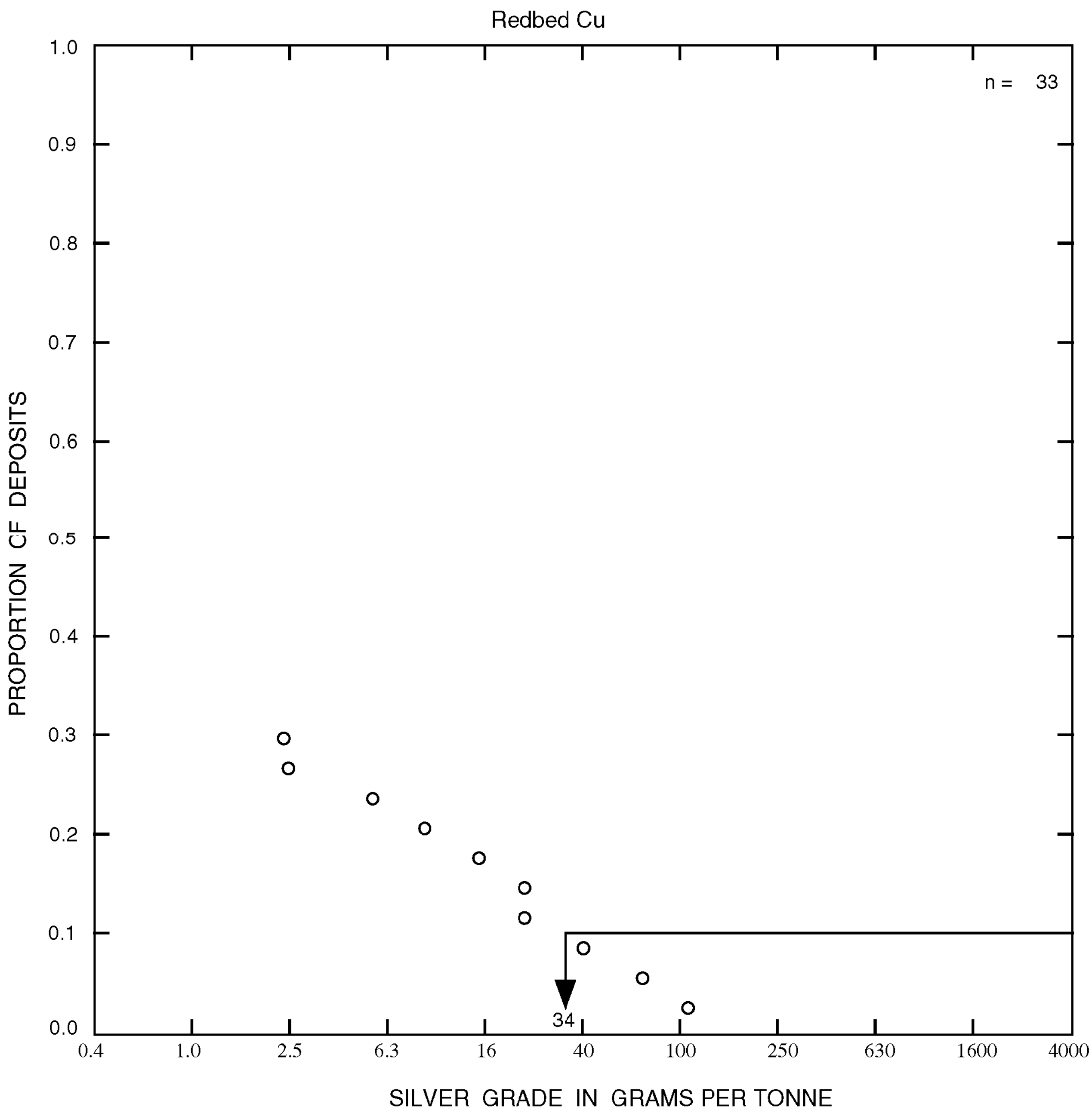

Figure 3. Silver grades
of redbed Cu deposits.

DESCRIPTIVE MODEL OF REVETT CU 30b.4, (Replaces Sediment-hosted Copper, 30b (Cox, 1986)

By Dennis P. Cox

APPROXIMATE SYNONYMS None

DESCRIPTION Revett copper deposits are stratabound mineralized bodies of disseminated copper and lead-zinc sulfides with silver, occurring on broad redox boundaries associated with color changes in redbed sequences.

GENERAL REFERENCES None

GEOLOGICAL ENVIRONMENT

Rock Types The characteristic stratigraphic setting for Revett copper deposits is a thick sandstone sequence. Sandstones are commonly red and contain white, gray or green alteration zones (Susura and others,1986). In Devonian and younger rocks, host beds commonly contain bitumins or other evidence for petroleum fluids. Evaporite beds are present in some cases. Deposits form as a result of mixing of copper-rich brines with ground water in equilibrium with pyrite (T.S. Hayes, oral commun. 2002) or with hydrocarbon fluids. The Dzhezkzagan deposit and other similar deposits and occurrences hosted by Carboniferous rocks are situated on the edge of the Chu Sari Su and Tengiz oil and gas fields. These fields have reservoir rocks of Carboniferous age (Popov, 1962). Gablina (1981) hypothesized that the Dzhezkzagan deposit was formed by mixing of brines with fluid hydrocarbons. Hayes and Einaudi (1986) postulated a reduced fluid as the reductant responsible for precipitation of the copper sulfides at Spar Lake Montana. Evidence for this fluid is the presence of pyrite and iron-rich calcite or ankerite in the sandstone (Hayes, 1990).

Among deposits in the Sediment-Hosted Copper Database (Cox and others, 2003), Revett deposits are most commonly hosted by sandstone, but 22 percent are contained in fine-grained clastic rocks (table 1).

Deposit Type	Number of deposits and occurrences	Sandstone, quartzite, arkose, conglomerate	Siltstone, shale, clay mudstone,	Limestone, dolomite, marl	Schist, phyllite, amphibolite, marble
Revett	31	77	22	0	<1
Redbed	155	85	12	2.5	<1
Reduced facies	100	29	41	28	2
Unclassified	102	30	20	25	25

Table 1. Host rocks of mineralization for individual occurrences by type expressed in percent of occurrences having a host rock description.

Textures Sandstones are well bedded and cross-laminated representing distal alluvial deposition and reworking in shallow marine or lacustrine basins. Localized stromatolitic layers as well as "sand pillows" or slump structures of sand into underlying silt beds are widespread (Garlick, 1988). "Ore rods" or mineralized fluid escape structures suggest that the underlying beds were the source of copper-rich solutions (Hayes and Einaudi, 1986).

At Dzhezkazgan, red and brown sandstones show cross-bedding and abundant erosional hiatuses with desiccation cracks and relict root systems. Broad lenses of green or gray sandstone in the redbeds are secondary and cross the bedding at low angles (Gablina, 1981).

Age Range No Archean deposits are known. Middle Proterozoic deposits are in the Belt Supergroup of Montana. The largest Revett deposit is Dzhezkazgan in the Lower Carboniferous of central Kazakstan.

Depositional Environment Most host rocks were deposited within 30 degrees of the paleoequator (Kirkham, 1989). They were deposited as fan deltas commonly entering closed-basin playas or a variety of coastal environments, shallow epicontinental seas, and related evaporite basins. Sediments deposited in these environments are favorable hosts for oxidizing, hematite stable, saline fluids capable of leaching and transporting copper. Nearby marine basins with oil and gas deposits are good guides to mineralization in redbeds as in Kazakstan (Gablina, 1981).

Tectonic Setting Revett copper deposits occur in fault-bounded basins in various settings, including rifts, intermontane basins in broad zones of extension, and foreland molasse basins. At

Dzhezkazgan fluid mixing and ore deposition took place over a paleo uplift at the margin of the redbed basin (Gablina, 1981).

Associated Deposit Types Sandstone lead deposits resemble the fringing galena sphalerite zone of Revett deposits, but there is no record of an actual association of these two types.

DEPOSIT DESCRIPTION

Mineralogy Principal minerals are chalcocite and other Cu_2S minerals, chalcopyrite, bornite, and native silver. Bitumens and oil residues may indicate the passage of fluid hydrocarbons. Metal sulfide zoning ranges from grain to deposit scale, reflecting directions of fluid flow and/or chemical gradients. Zones of Cu_2S minerals, bornite, chalcopyrite, pyrite, galena, and sphalerite are arranged across redox boundaries with chalcocite on the oxidized side and pyrite and Pb-Zn sulfides on the reduced side. Most common gangue minerals are quartz, iron-rich calcite, and aragonite.

Texture/Structure Ore minerals are disseminated as late cement in lenticular bodies. Mineralized replacement features may follow zones with highest prelithification permeability. Mineral zones also commonly follow roll fronts. Fluid escape structures are mineralized at Spar Lake and other deposits (Hayes and Einaudi, 1986).

Alteration. Where oxidized brines have passed through redbed sequences in the source-rock area of redbed deposits, lavender-gray, hematite and magnetite bearing, albite-rich, carbonate-free rocks depleted in K, Ca and most base metals are formed (Hayes, 1990).

Reduced fluids in redbeds produce pale gray or green rocks with disseminated pyrite, Fe-calcite, ankerite and chlorite. This alteration is equivalent to that accompanying the distal chalcopyrite-pyrite and galena-bearing zones of the copper deposits (Hayes, 1990).

Ore Controls. Beds with high pre-ore permeability are the major ore controls. Redox fronts (roll fronts) in ore-forming fluids control copper deposition. At Spar Lake, fluid mixing responsible for ore deposition occurred as fluids move vertically through the section (Hayes, 1990). Syndepositional faulting acts as ore control in Montana deposits(Hayes and Einaudi, 1986). At Dzhezkazgan, reduced fluids moved laterally down the shallow dip of the beds (Gablina, 1981).

Weathering Surface exposures of sulfides weather to hydroxides and carbonates, and may even be leached completely.

Geochemical Signature Cu, Ag, Pb, Zn, (Mo, V, U). Some deposits weakly radioactive. Kazak deposits contain Mo and Re.

EXAMPLES

Spar Lake, USMN	(Hayes and Einaudi, 1986)
Montanore-Rock Creek, USMT	(Adkins, 1993)
Dzhezkazgan, USKZ	(Gablina, 1981)

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Model 30b.4

GRADE AND TONNAGE MODEL OF REVETT Cu

By Dennis P. Cox and Donald A. Singer

(Replaces Model 30b of Mosier and others (1986)

COMMENTS: A deposit is defined as one or more separate orebodies separated from its nearest neighbor by more than 2,000 m. Rock Creek deposit includes Montanore, Rock Lake, Copper Gulch, Horizon Basin, and Rock Peak. Copper grade is corelated with silver grade (r = 0.77, n = 8) at the five-percent level.

DEPOSITS

Name	Country	Name	Country
Big Indian	USUT	Niagara	USID
Cashin	USCO	Rock Creek	USMT
Dzhezkazgan	KAZN	Snowstorm	USID
JF	USMT	Spar Lake	USMT
Lisbon Valley	USUT	Vermillion River	USMT
Missoula National	USID		

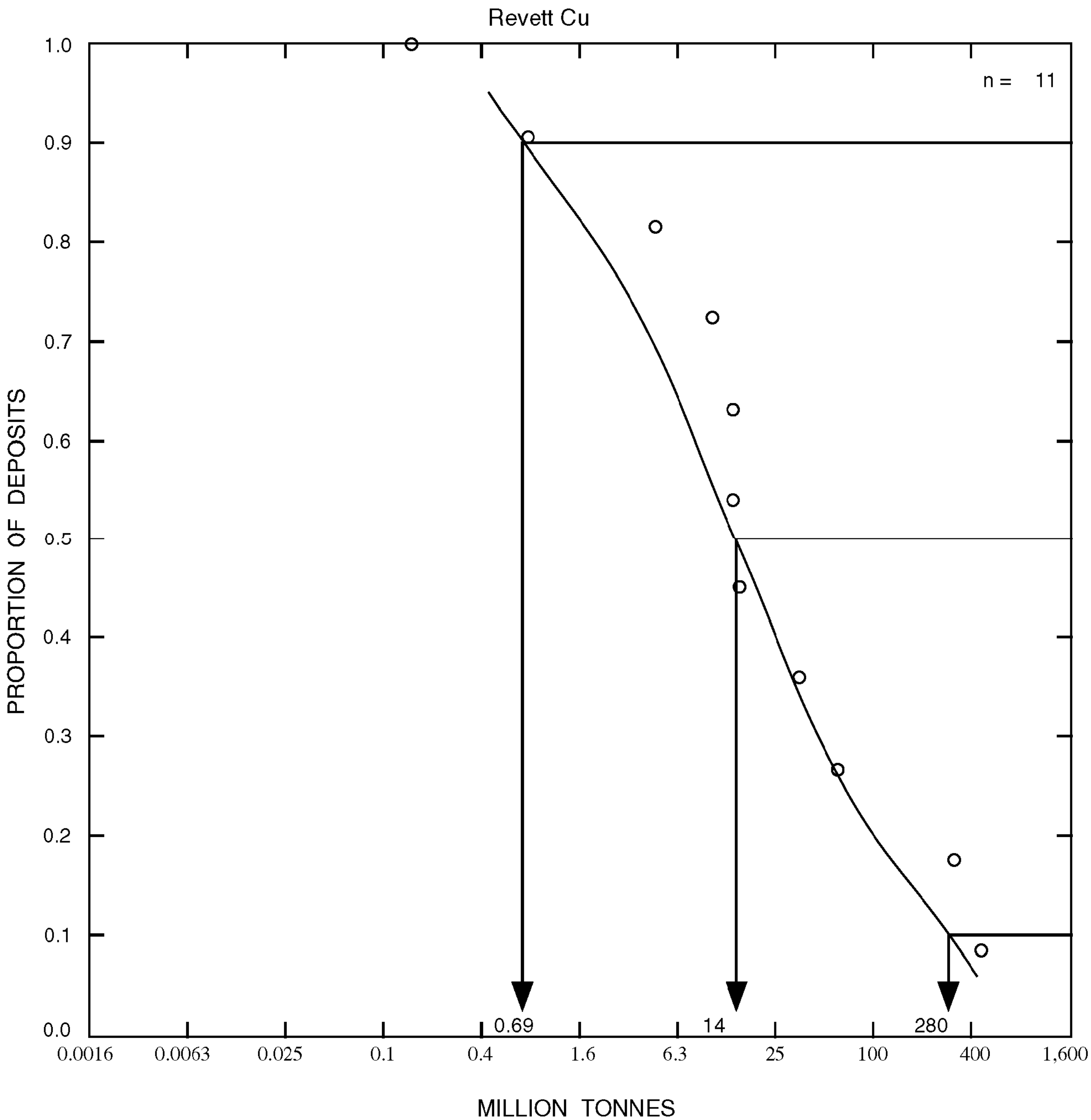

Figure 1. Tonnages of Revett Cu deposits.

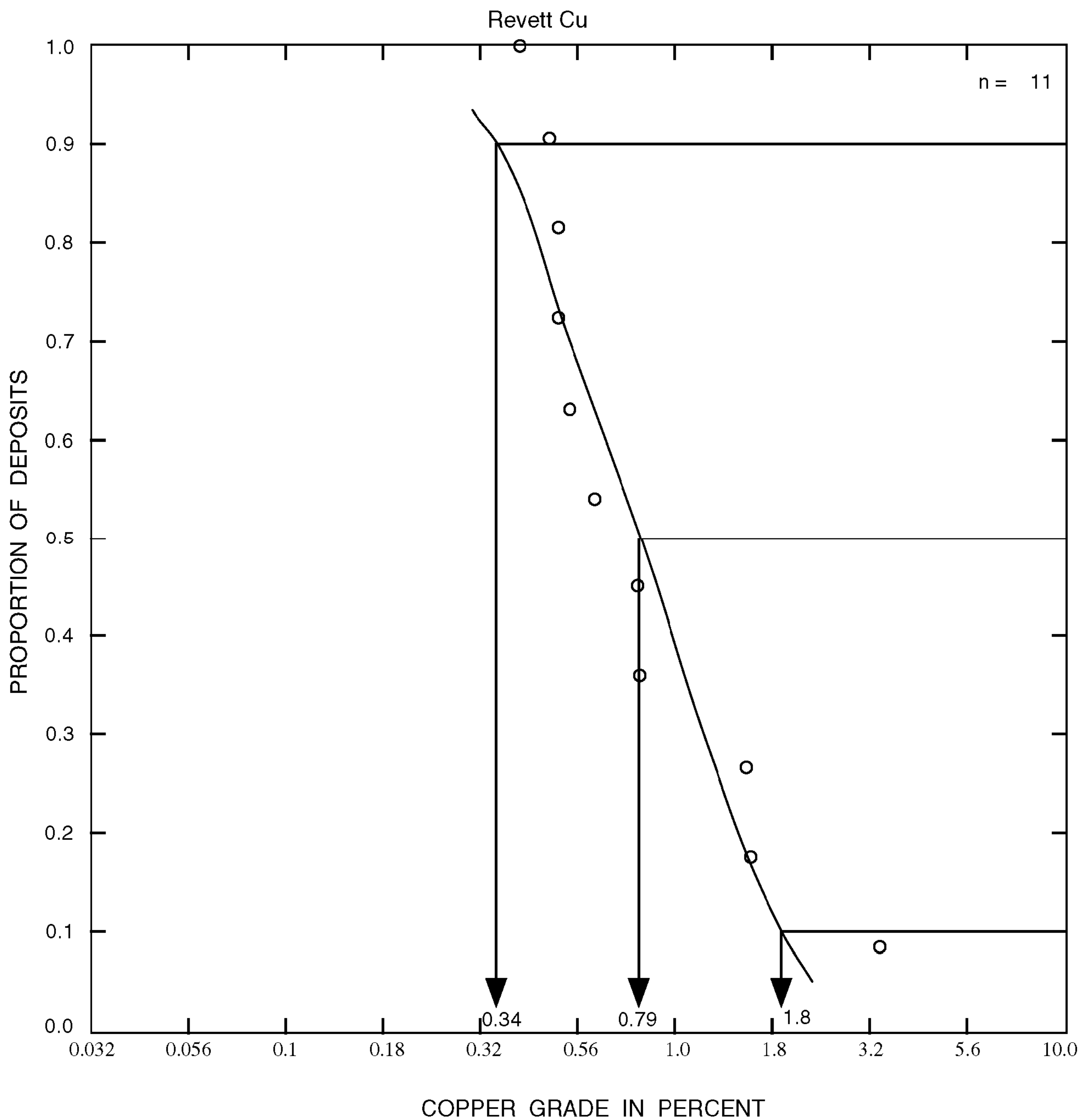

Figure 2. Copper grades of Revett Cu deposits.

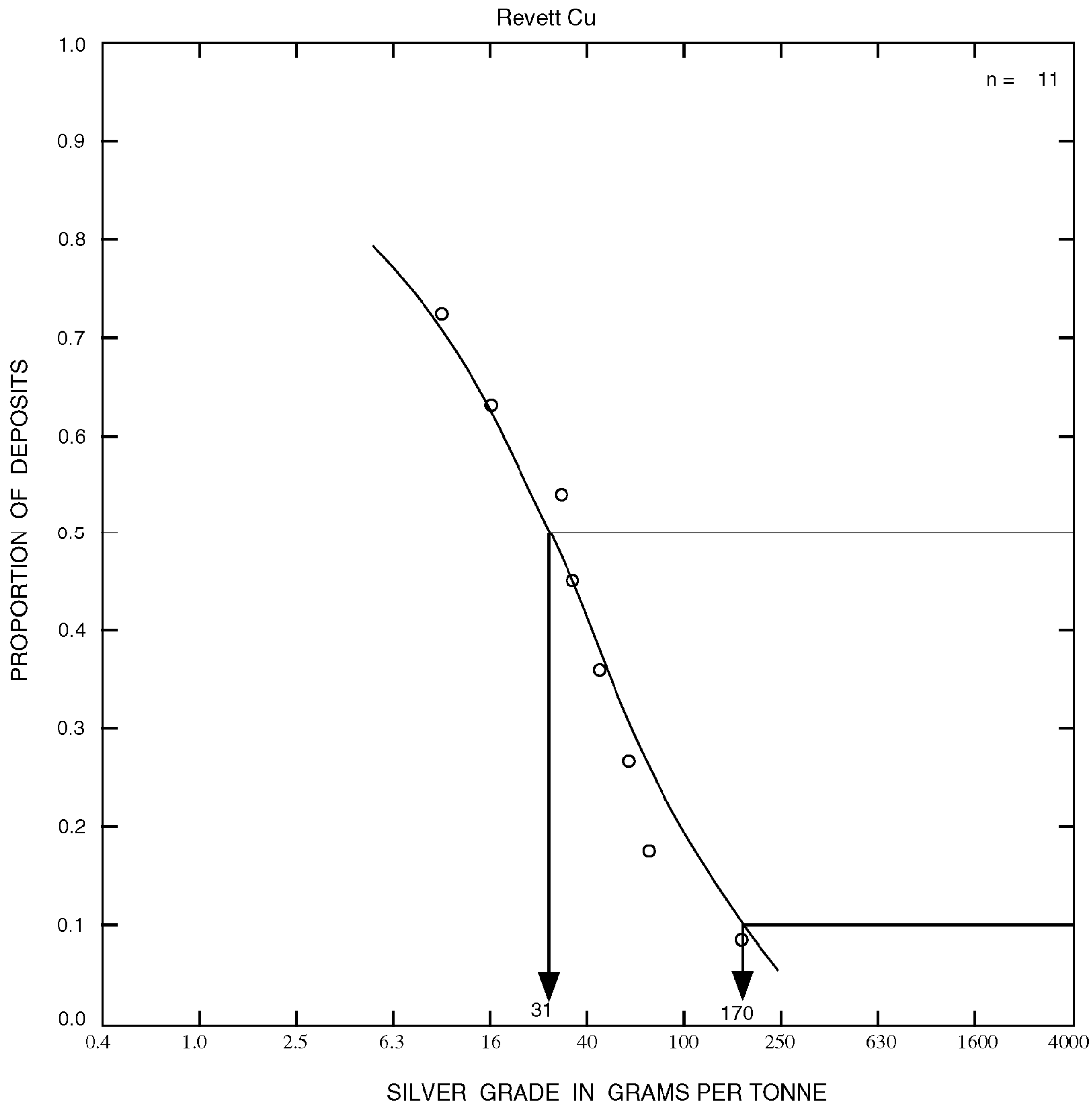

Figure 3. Silver grades of Revett Cu deposits.